A Notional Battlespace for Simulating and Testing Dynamic Wireless Networks

GRADUATE RESEARCH PROJECT

David E. Stookey, Major, USAF

AFIT/IC4/ENG/06-06

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

AFIT/IC4/ENG/06-06

A NOTIONAL BATTLESPACE FOR SIMULATING AND TESTING DYNAMIC WIRELESS NETWORKS

GRADUATE RESEARCH PROJECT

Presented to the Faculty

Department of Electrical & Computer Engineering

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of C4I Systems

David E. Stookey

Major, USAF

June 2006

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

AFIT/IC4/ENG/06-06

A NOTIONAL BATTLESPACE FOR SIMULATING AND TESTING DYNAMIC WIRELESS NETWORKS

David E. Stookey

Major, USAF

Approved:

/SIGNED/	2 Jun 2006
Scott R. Graham, Major, USAF, PhD (Chairman)	Date
/SIGNED/	2 Jun 2006
Kenneth M. Hopkinson, PhD, USAF (Member)	Date
/SIGNED/	2 Jun 2006
Robert F. Mills, PhD, USAF (IDE/C4I Advisor)	Date

ABSTRACT

Communications are critical to many operations and functions. The US military relies on a complex mesh of communication circuits, comprised of wired and wireless links. While mobile communication is necessarily wireless, currently mobile communication occurs in a rigid structure of centrally managed, dedicated links. Future military communication will require dynamic wireless networks where more data is routed and transported in an opportunistic method in the battlespace. Researchers are exploring various topics related to Dynamic Wireless Networks, including Topology Control, Dynamic Mobile Routing, and Hybrid Communication Links. Testing the military application of these research areas requires an understanding of the battlespace and the assets and data flow requirements within the battlespace.

This paper provides a scenario and data pertaining to a notional battlespace for use in testing, simulating and further research efforts into the implementation and use of dynamic wireless network application for the US military. First defining a battlespace, then describing assets that might be found in a generic battlespace. The paper concludes with tables, representing realistic data flow requirements and assets for a specific notional scenario for use in building a simulation to further test aspects of dynamic wireless networking in the battlespace.

AFIT/IC4/ENG/06-06

To my wife and family who helped make this year enjoyable

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Major Scott Graham for his guidance and support throughout the course of this research effort. It was his motivation that identified this topic for my research, and it proved to be very enlightening. I would also like to thank Dr Hopkinson for his encouragement and insight in making this project take root and form. Without their assistance, I could not have completed this effort.

Dave Stookey

Table of Contents

Abstract iv
Acknowledgments vi
List of Figures ix
Introduction 1
Background 2
Ground Assets 4
Air Assets 12
A/OA-10 Thunderbolt - Close Air Support 12
F-16 Fighting Falcon - Multi-role Fighter 14
E-3 Airborne Warning and Control System (AWACS) 15
E-8 Joint Surveillance Target Attack Radar System (Joint STARS) 16
KC-135 Stratotanker - Air Refueling 17
UAVs 18
MQ-1 Predator 18
Global Hawk 20
Space Assets 21
DSCS 21
GPS 23
Milstar 25
A Notional Battlespace For Dynamic Wireless Network Simulation/Testing 27
Mini Scenario: 29
Network Tasking Order 30
Network Predictability: Predicting Node Location and State 31
Current Networks 32
Dynamic Wireless Network 33
Sources of Location Information 37
Communications Tasking Order (CTO). 37
Air Tasking Order 37
Common Operating Picture 39
Blue Force Tracking 40

A hypothetical future scenario to be used to study dynamic wireless networks 42
Simplifying the Notional Battlespace 44
Assumptions: 47
Network Tasking Order 53
Battle Rhythm Products 54
Conclusion 57
Bibliography 59
Appendix A: Data Flow Matrix A
Appendix B: Communications Capacity Matrix B
Appendix C: Notional Battle Rhythm Matrix C1-2
Appendix D: Graphic Location D1-11

List of Figures

Figure 1: The Stryker Brigade Combat Team Organization Chart 5
Figure 2: Stryker Vehicle with .50 gun 6
Figure 3: Stryker with protective grating 6
Figure 4: Stryker Brigade Subnets 9
Figure 5: Representation of Higher (WAN) & Lower Tactical Internet 10
Figure 6: Global Broadcast System Overview [8] 12
Figure 7: A-10 Two-Ship 13
Figure 8: F-16 Fighting Falcon 14
Figure 9: E-3 Air Warning and Control System (AWACS) [11] 15
Figure 10: E-8 Joint Surveillance Target Attack Radar System (Joint STARS) 16
Figure 11: KC-135 Stratotanker 17
Figure 12: MQ-1 Predator 18
Figure 13: Global Hawk UAV 20
Figure 14: DSCS Satellite 21
Figure 15: DSCS Overview [16] 22
Figure 16: GPS Satellite 23
Figure 17: Milstar Satellite 25
Figure 18: Representation of Battlespace Communication Links 32
Figure 19: Two Dimensional RF Coverage 33
Figure 20: Cell Phone Tower Coverage 34
Figure 21: Satellite Tracking Equipment 41
Figure 22: Tactical Data Link 16 Representation [28] 46
Figure 23: Possible Data Routes 49
Figure 24: Input stream for data destined for platoon 50
Figure 25: Possible Connectivity 1. 55
Figure 26: Possible Connectivity 2. 56
Figure 27: Possible Connectivity 3. 57

A NOTIONAL BATTLESPACE FOR SIMULATING AND TESTING DYNAMIC WIRELESS NETWORKS

Introduction

In military operations, communication is critical. Today, the US military relies on a complex mesh of communication circuits, comprised of wired and wireless links. Mobile communication is necessarily wireless, but currently the mobile communication occurs in a very rigid structure of dedicated links which may change daily, but is centrally controlled. Future military communication will require dynamic wireless networks where more data is routed and transported in an opportunistic method in the battlespace. There is a great deal of research still needed to address pertinent questions about the reliability, dependability and robustness of dynamic wireless networks before it really can be applied in this context. Researchers in the Electrical and Computer Engineering Department of the Air Force Institute of Technology are exploring various topics related to Dynamic Wireless Networks, including Topology Control, Dynamic Mobile Routing, Bandwidth Optimization, and Hybrid Communication Links.

This paper provides a scenario and data pertaining to a notional battlespace for use in testing, simulating and further research efforts into the implementation and use of dynamic wireless network application for the US military. First defining a battlespace, then describing some of the assets that might be found in a generic battlespace. The paper concludes with tables, representing actual numbers and assets for a specific notional scenario that could be used to build a simulation to further test other aspects of dynamic wireless networking in the battlespace.

Background

Dynamic wireless networks might be defined as "a collection of mobile nodes that are dynamically and arbitrarily located in such a manner that the interconnections between nodes are capable of changing on a continual basis."[1: 46] Today, most high data rate wireless technology can be made to work reasonably well for single, fixed links, but the survivability, robustness and autonomous reconfiguration in a dynamic, mobile network is an area where considerable further research is needed. Developing models, tools and experiments in estimating and predicting future network states requires the researcher to have some understanding of a given network state from which to build simulations. This research area could apply to any dynamic network. However this paper/effort will focus on a tactical military application of this technology.

In US operations, Combatant Commanders have been assigned large areas of the world that they have overall responsibility for. Joint Task Forces are organized and assigned areas of responsibility within the Combatant Commander's jurisdiction and a Joint Force or Joint Task Force (JTF) Commander (JFC) is designated and given authority from that Combatant Commander. The JFC may be assigned responsibility for an area affected by a natural disaster, a specific region combating piracy on the open seas or in warfighting, an area within an overall theater of operations. During Operations ENDURING and IRAQI FREEDOM, there were a number of supported JFCs established by CENTCOM to prosecute the war.

Consider a battle field or a particular area of responsibility. A large and ever changing number of units, vehicles, airplanes and other mobile assets, both friendly and enemy, occupy a theater of conflict. The level of conflict, the debate of right or wrong, state vs. tribal or inter-state, and weaponry are all left outside the boundary of this research. Suffice it to say there will be a large, but finite number of actors in/on the theater, and in today's information age, it is without doubt that information systems and information superiority will be of primal importance for all but the most remote third-world conflicts. An area of responsibility, theater of operations or battlespace (hereinafter called battlespace) could be described by the territory, the assets under the joint task force commanders control, or the geo-political boundaries that describe the conflict or trouble spot. Within many Department of Defense papers, the five-dimensional battlespace has been defined as Air, Land, Sea and Space fused with time and cyberspace [2]. DoD Joint Publications define it as:

> The environment, factors, and conditions that must be understood to successfully apply combat power, protect the force, or complete the mission. This includes the air, land, sea space and included enemy and friendly forces: facilities, weather, terrain, the electromagnetic spectrum, and the information environment within the operational area and areas of interest. [3: 71]

There many variations of these definitions available from a wide variety of sources. For the research at hand, we will define the battlespace as the five-dimensions discussed above, focusing on the known net centric nodes that are part of the battlespace as well as the information flow and situational awareness within that space.

To understand the data and information flow in a battlespace, we can look at the assets, processes and systems that might be found in a notional battlespace. A specific location or specific conflict is irrelevant. This research will focus on a generic case. Under current US battle doctrine, assuming the conflict has escalated to the point where National Command Authority has sought military action, the armed forces would respond with all the necessary force required to successfully prosecute and win a conflict. In most conflicts, the military would bring air, land, sea, and space forces. In our generic case, we'll assume the conflict required land, air, and space forces. Sea lift is almost always used in some degree or another to take the fight to other nations. However, in this notional battlespace, we'll focus on land, air and space assets, because from the perspective of dynamic communications, sea-based assets are semantically equivalent to land based systems. Focusing on the Army's Future Combat Forces, we'll use a Stryker Brigade Combat Team as the notional ground force. Air assets commonly found in a battlespace might include fighters, bombers, refuelers, intelligence, surveillance and reconnaissance platforms, as well as space assets. A greater explanation of some of these assets is now presented.

Ground Assets

Since 2003, the US Army has gone through a significant transformation process in a move to become the most technologically advanced army in the world. They are in the process of moving from the Corps, Division, Battalion model to one of modular brigade level combat teams. In creating modular, combined arms maneuver brigade combat teams, the Army has focused on three types: Heavy (armored/mechanized), Stryker

and Infantry. As part of this transformation, the Army is migrating capabilities that were previously found at divisions and corps to the Brigade Combat Teams (BCTs) – the building block of combat forces in the Future Force. For our research in creating this notional battlespace we will use a Stryker Brigade Combat Team (Stryker BCT or SBCT) for our ground combat unit. The Stryker BCT is an organic combined-arms team with approximately 3,500 soldiers assigned. The Stryker BCT has one organic Reconnaissance, Surveillance, Target Acquisition (RSTA) squadron, three infantry battalions, one field artillery battalion, one brigade-support battalion, an engineer company, a military intelligence company and a signal company. A basic unit diagram might look like:

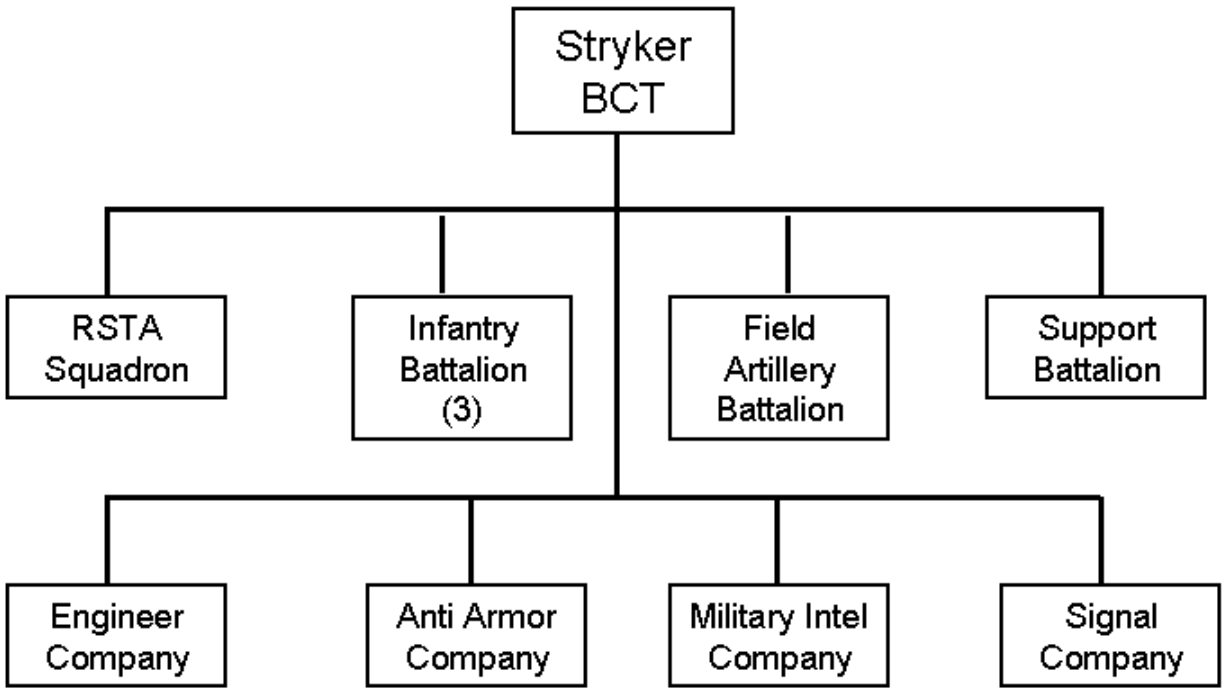


Figure 1 The Stryker Brigade Combat Team Organization Chart [4]

All organic units are mobile, part of the Brigade network and are assigned various versions of the Stryker vehicle. The RSTA squadron is intended to provide accurate and timely information over a large operation area and offer organic unmanned aerial vehicle (UAV) capability to the Stryker BCT to facilitate this Intelligence, Surveillance and Reconnaissance (ISR) gathering effort.

Figure 2 Stryker Vehicle with .50 gun

The Stryker was the combat vehicle of choice for the Army's Interim Brigade Combat Teams (IBCTs) and the name has now been adopted as the official name of these units. It is a highly deployable-wheeled armored vehicle that combines firepower, battlefield mobility, survivability and versatility, with reduced logistics requirements.

The vehicle was named in honor of two Medal of Honor recipients: Private First Class Stuart S. Stryker, who served in World War II, and Specialist Robert F. Stryker, who served in Vietnam. The Stryker BCT provides the joint and multinational force commander increased operational and tactical flexibility to execute the fast-paced, distributed, non-contiguous operations envisioned across the full spectrum of conflict.

Figure 3: Stryker with protective grating

Stryker is a 19-ton wheeled armored vehicle program that has expanded into a family of ten different vehicles. The Stryker can be deployed by C-130 aircraft and be combat-capable upon arrival in any contingency area. The Stryker family includes the Infantry Carrier Vehicle, Mobile Gun System, Anti-Tank Guided Missile Vehicle, Mortar Carrier Vehicle, Reconnaissance Vehicle, Fire Support Vehicle, Engineer Squad Vehicle, Commander's Vehicle, Medical Evacuation Vehicle, and a Nuclear, Biological and Chemical (NBC) Reconnaissance Vehicle. The vehicles have robust armor protection, can sustain speeds of 60 miles-per-hour, have parts commonality and self-recovery abilities and also have a central tire inflation system. The Infantry Carrier Vehicle carries a nine-man infantry squad with a vehicle crew of two and has a Remote Weapon Station with an M2 .50 caliber machine gun or MK19, 40 mm grenade launcher. Intrinsic to the design of this vehicle was the incorporation of forward-looking technology, including the most advance digital communications networks available in land forces today. A typical Stryker BCT uses 6 separate voice/data networks to communicate among the brigade combat team itself and its three maneuver battalions. The Stryker BCT has been organized and equipped with a digital communications network that connects nearly every vehicle of the brigade into a single, relatively seamless network. The lower tactical internet (lower in bandwidth and short-range RF communications systems) connects 75 percent of the unit's vehicles. The higher tactical internet links brigade and battalion tactical operations centers, and other C2 nodes into a single high-capacity network [5: 31]. The unit is also equipped with

current-generation Army digital terrestrial and satellite communications (SATCOM) systems, and the current generation of evolving Army battle command systems.

With respect to the network and data details of the Stryker BCT, the Stryker Brigade Combat Team network consists of five subnets, roughly shown in Figure 4 below. The Wide Area Network is a SATCOM based system that can use three different satellite systems for connectivity amongst the unit's C2 vehicles: 1) MILSTAR Extremely High Frequency (EHF) connecting the vehicle's Secure Mobile Antijam Reliable Tactical Terminals (SMART-Ts), 2) UHF military satellite communications using a Spitfire terminal, and 3) commercial point-to-point satellite links using terminals called Trojan Spirit. These terminals provide higher level assets reach-back connectivity to the US and enable higher bandwidth applications such as intelligence and UAV data to move between tactical units. Reach-back represents the capability to exchange data with remote commanders, analysts, and operators stationed outside of the theater. This capability decreases the number of people who must be deployed in the theatre as well as the logistics tail associated with them and is highly desirable. However, the communications link between deployed and non-deployed operators must be large enough, fast enough, and sufficiently robust to ensure that the deployed operators are not stranded without the requisite assistance from the non-deployed operators.

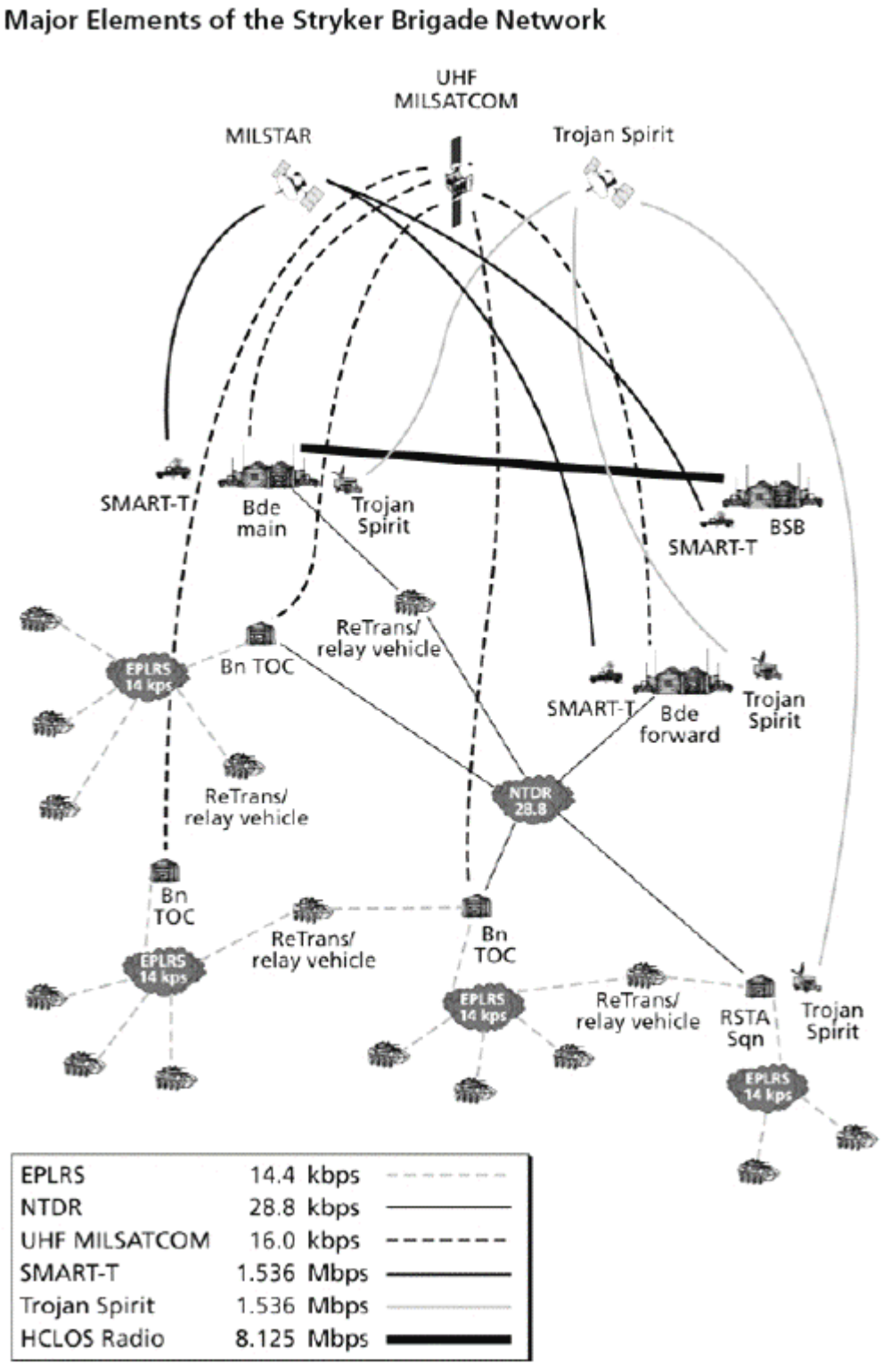


Figure 4: Stryker Brigade Subnets [5: Figure 4-1]

The Tactical Internet (TI) network is composed of Enhanced Position Location Reporting Radio Systems (EPLRS) and is a low-bandwidth (14.4kps mean, 56.6 kps max) terrestrial network that carries situational awareness data and provides text messaging capability throughout the SBCT. This network has been depicted as shown in this briefing chart presented by the Army's Soldier Program Executive Office December 2004:

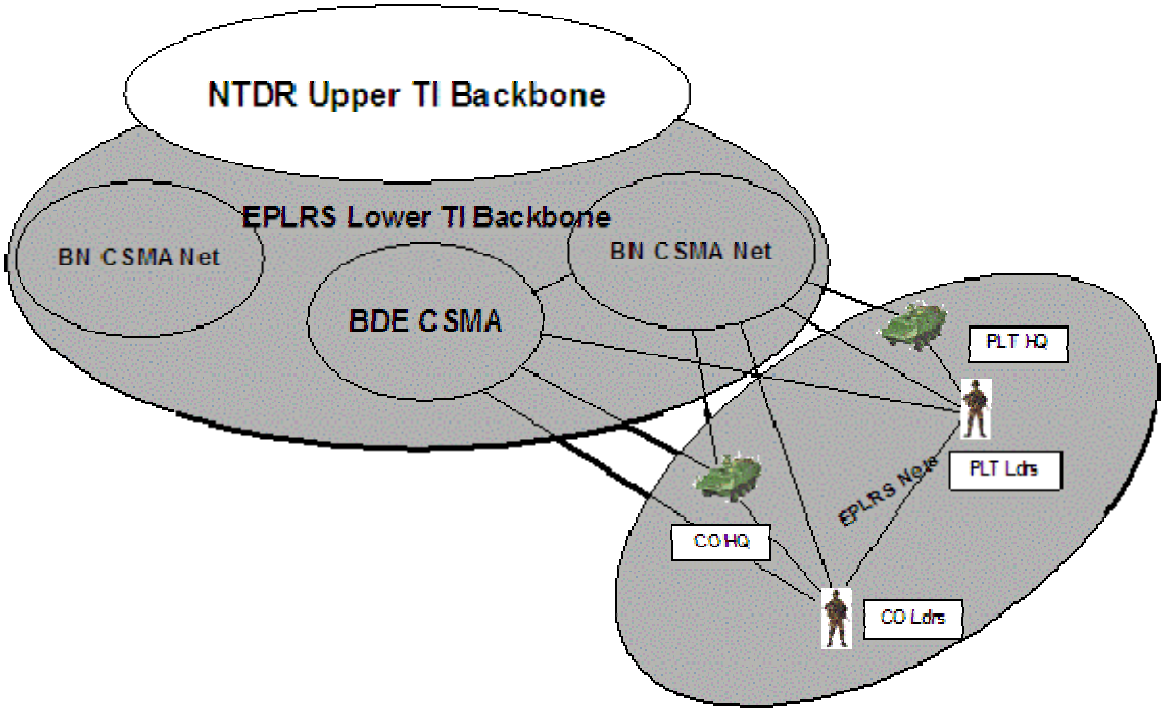


Figure 5: Representation of Higher (WAN) & Lower Tactical Internet (SBCT) [6]

The TI network is limited to line-of-sight and provides digital communications to vehicles while on the move or stopped. The voice component of this network uses the Combat Net Radio – FM voice Single Channel Ground and Airborne Radio System, man-portable radios. Subnets exist for squad, platoon, company, battalion, and brigade levels. EPLRS allows for the automatic generation and distribution of unit, vehicle and

personnel location information from and to all EPLRS-equipped vehicles in the SBCT. This information and text messages (instant messaging) are accessible to soldiers using the Force XXI Battle Command, Brigade-and-Below (FBCB2) system [7: 46]. EPLRS has automatic relay and dynamic reconfiguration capabilities, leading to a robust network structure for situational awareness data. However as is common with RF systems, line of sight, range and bandwidth constraints can lead to less reliable C2 messaging and data transmissions. Also critical to note, with voice traveling over CNR assets, the voice net is relatively free for urgent messages and key decision information because routine situational awareness and data traffic is routed over EPLRS.

The final two subnets in the SBCT network are the SATCOM WAN and Global Broadcast System. The satellite communications provide communications between battalion and above tactical operations centers and HQ as well as other rear echelon forces. The satellite communications capability is mounted in C2 vehicles and offers unit leadership the opportunity to use low-bandwidth secure communications of the MILSTAR satellite constellation, the higher-bandwidth, less secure Defense Satellite Communications System and more responsive, leased commercial satellite links. These circuits vary in size from 28.8 kbps to 8Mbps, depending on the link, the equipment and the data.

The Global Broadcast System (GBS) is a high bandwidth distribution system employed by DoD units to send large data chunks to forward units using the same technology as commercial satellite television broadcasts. The bandwidth can be as much as 24 Mbps per transponder and the Stryker BCT can send large streams to down-range units in relatively short time.

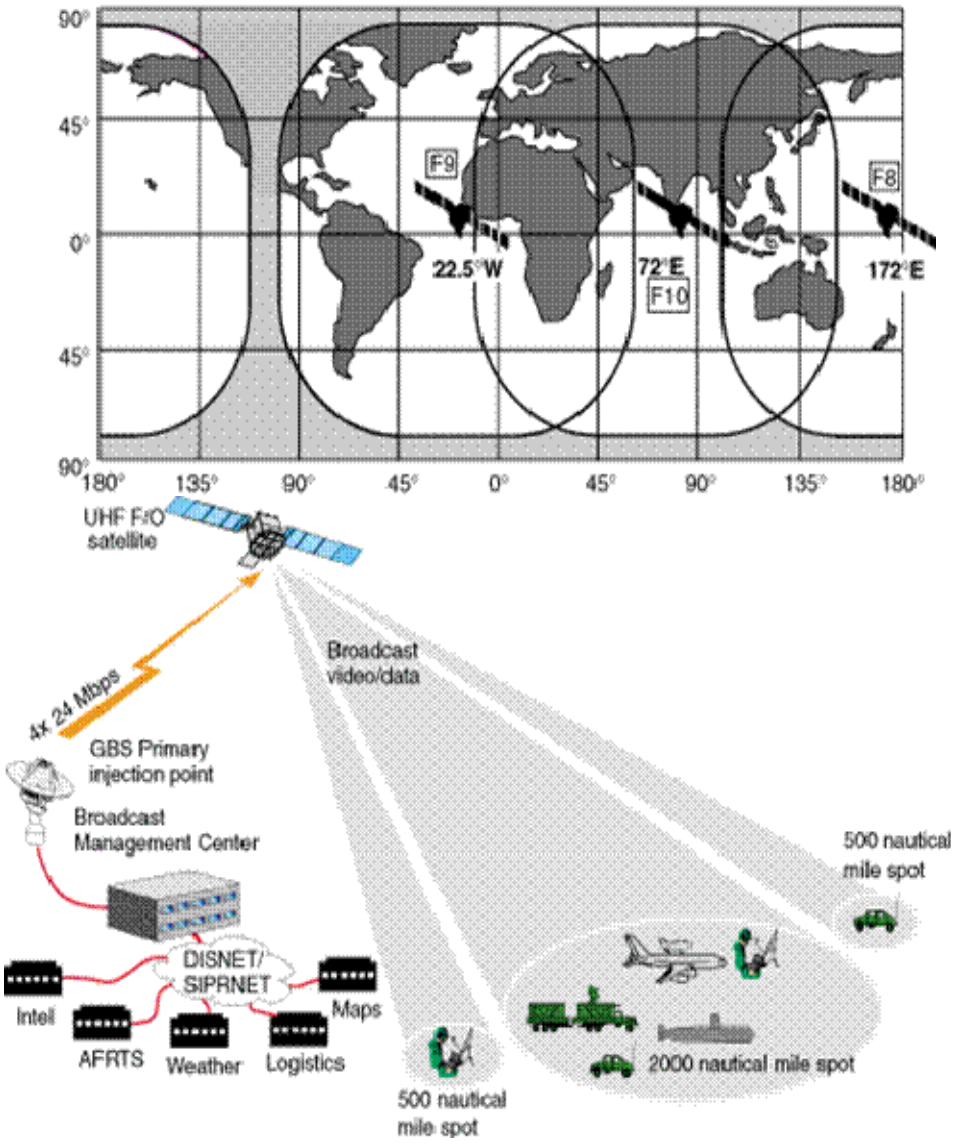


Figure 6: Global Broadcast System Overview [8]

Air Assets

While numerous aircraft may participate in a combat scenario, we have chosen a small representative sample of aircraft in order to highlight the communication requirements and capabilities each brings to the conflict.

A/OA-10 Thunderbolt - Close Air Support

A squadron of A-10s could be assigned to provide close air support to ground forces.

The A/OA-10 Thunderbolt II is the first Air Force aircraft specially designed for close air

support of ground forces. They are simple, effective and survivable twin-engine jet aircraft that can be used against all ground targets, including tanks and other armored vehicles.

Figure 7: A-10 Two-Ship

The A-10 and OA-10 have excellent maneuverability at low air speeds and altitude, and are highly accurate weapons-delivery platforms. They can loiter near battle areas for extended periods of time and operate under 1,000-foot ceilings (303.3 meters) with 1.5-mile (2.4 kilometers) visibility. Their wide combat radius and short takeoff and landing capability permit operations in and out of locations near front lines. The redundant primary structural sections allow the aircraft to enjoy better survivability during close air support than did previous aircraft. The aircraft can survive direct hits from armor-piercing and high explosive projectiles up to 23mm. Their self-sealing fuel cells are protected by internal and external foam. Avionics equipment includes communications, inertial navigation systems, fire control and weapons delivery systems, target penetration aids and night vision goggles. Their weapons delivery systems include heads-up displays that indicate airspeed, altitude, dive angle, navigation information and weapons aiming references; a low altitude safety and targeting enhancement system (LASTE) which provides continuously computed impact

point freefall ordnance delivery; and Pave Penny laser-tracking pods under the fuselage [9].

Figure 8: F-16 Fighting Falcon

F-16 Fighting Falcon - Multi-role Fighter

A squadron of F-16s could be assigned the air interdiction mission and provide some strike capability. The F-16 Fighting Falcon is a compact, multi-role fighter aircraft. It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack. It provides a relatively low-cost, high-performance weapon system for the United States and allied nations. In an air combat role, the F-16's maneuverability and combat radius (distance it can fly to enter air combat, stay, fight and return) exceed that of all potential threat fighter aircraft. It can locate targets in all weather conditions and detect low flying aircraft in radar ground clutter. In an air-to-surface role, the F-16 can fly more than 500 miles (860 kilometers), deliver its weapons with superior accuracy, defend itself against enemy aircraft, and return to its starting point. The Avionics systems include a highly accurate inertial navigation system in which a computer provides steering information to the pilot. The plane has UHF and VHF radios plus an

instrument landing system. It also has a warning system and modular countermeasure pods to be used against airborne or surface electronic threats. The fuselage has space for additional avionics systems [10].

E-3 Airborne Warning and Control System (AWACS)

Some of the Air Force's assets are in high demand for a variety of roles and missions throughout the world, but are relatively few in numbers within the Department of Defense. Some of which are discussed below.

Figure 9 E-3 Air Warning and Control System (AWACS) [11]

The E-3 Airborne Warning and Control System (AWACS) which provides both airborne surveillance and command and control (C2) functions for tactical and air defense forces. The E-3 offers superior surveillance capabilities. Equipped with a "look-down" radar, the AWACS can separate airborne targets from the ground and sea clutter returns that confuse other present-day radars. Its radar "eye" has a 360-degree view of the horizon, and at operating altitudes can see more than 320 kilometers (200 miles). It also can detect and track both air and sea targets simultaneously. In its

tactical role, the E-3 provides quick-reaction surveillance and C2 necessary to manage both tactical and defensive fighter forces. The E-3 can detect and track hostile aircraft operating at low altitudes over all terrain, and can identify and control friendly aircraft in the same airspace. In its strategic defense role, the E-3 provides the means to detect, identify, track and intercept airborne threats. The basic E-3 aircraft is a militarized version of the Boeing 707-320B commercial jetliner airframe and is distinguished by the addition of a large, rotating rotodome containing its radar antenna and identification friend-or-foe (IFF) and data-link fighter-control (TADIL-C) antennas. Its mission system includes surveillance radar, navigation, communications, data processing, identification and display equipment. The heart of the information processing network is an airborne version of the IBM command and control multiprocessing computer [11].

E-8 Joint Surveillance Target Attack Radar System (Joint STARS)

Figure 10 E-8 Joint Surveillance Target Attack Radar System (Joint STARS)

Another platform in high demand is the E-8C Joint Surveillance Target Attack Radar System (Joint STARS). The Joint STARS is a long-range, air-to-ground surveillance

system designed to locate, classify and track ground targets in all weather conditions. As an airborne battle management and command and control platform, it conducts ground surveillance to develop an understanding of the enemy's situation and to support attack operations and targeting that contributes to the delay, disruption and destruction of enemy forces. While flying in friendly airspace, the joint Army-Air Force program can look deep behind hostile borders to detect and track ground movements in both forward and rear areas. These capabilities make Joint STARS effective for dealing with any contingency, whether actual or impending military aggression, international treaty verification, or border violation. Joint STARS evolved from U.S. Air Force and Army programs to develop, detect, locate and attack enemy armor at ranges beyond the forward area of troops and is a key element in the US arsenal [12].

KC-135 Stratotanker - Air Refueling

The KC-135 Stratotanker's principal mission is air refueling. This unique asset greatly enhances the Air Force's capability to accomplish its primary missions of Global Reach and Global Power. It also provides aerial refueling support to Air Force, Navy and

Figure 11 KC-135 Stratotanker

Marine Corps aircraft as well as aircraft of allied nations. One crewmember, known as the boom operator, is stationed in the rear of the plane and controls the refueling boom during in-flight air refueling. A cargo deck above the refueling system can hold a mixed load of passengers and cargo. Depending on fuel storage configuration, the KC-135 can carry up to 83,000 pounds (37,648 kilograms) of cargo. Through the years, the KC-135 has been altered to do other jobs ranging from flying command post missions to reconnaissance. RC-135s are used for special reconnaissance. Air Combat Command operates the OC-135 as an observation platform in compliance with the Open Skies Treaty. Over the next few years, the aircraft will undergo upgrades to expand its capabilities and improve its reliability. Among these are improved communications, navigation and surveillance equipment to meet future civil air traffic control needs [13].

UAVs

MQ-1 Predator

The MQ-1 Predator is a medium-altitude, long-endurance, remotely piloted aircraft. The MQ-1's primary mission is interdiction and conducting armed reconnaissance against perishable targets. It also acts as the Joint Forces Air Component Commander-owned theater asset for reconnaissance, surveillance and target acquisition in support of the Joint Forces commander. A fully operational MQ-1

Figure 12 MQ-1 Predator

Predator system consists of four aircraft (with sensors), a ground control station, a Predator Primary Satellite Link, and approximately 55 personnel for deployed 24-hour operations. The basic crew for the Predator is one pilot and two sensor operators. They fly the aircraft from inside the ground control station via a C-Band line-of-sight data link capable of 4.5 Mbps, or a Ku-Band satellite data link with a T-1 or 1.54 Mbps data rate capability, for beyond line-of-sight flight. The aircraft is equipped with a color nose camera (generally used by the pilot for flight control), a day variable-aperture TV camera, a variable-aperture infrared camera (for low light/night), and a synthetic aperture radar for looking through smoke, clouds or haze. The cameras produce full motion video while the SAR produces still frame radar images. The MQ-1 Predator carries the Multi-spectral Targeting System with inherent AGM-114 Hellfire missile targeting capability and integrates electro-optical, infrared, laser designator and laser illuminator into a single sensor package. The Predator can operate on a 5,000 by 75 feet (1,524 meters by 23 meters), hard surface runway with clear line-of-sight. The ground data terminal antenna provides line-of-sight communications for takeoff and landing. An alternate method of employment, Remote Split Operations, employs a smaller version of the Guidance Control System (GCS) called the Launch and Recovery GCS. The Local GCS conducts takeoff and landing operations at the forward deployed location while the CONUS based GCS conducts the mission via extended communications links. The aircraft includes an ARC-210 radio, an APX-100 IFF/SIF with Mode 4, an upgraded turbo-charged engine and glycol-weeping “wet wings” for ice mitigation. The latest upgrade includes fuel injection, longer wings, dual alternators

and other improvements. The "M" is the Department of Defense designation for multi-role and "Q" means unmanned aircraft system. The "1" refers to the aircraft being the first of a series of purpose-built remotely piloted aircraft systems. The Predator system was designed in response to a Department of Defense requirement to provide persistent intelligence, surveillance and reconnaissance information to the warfighter [14].

Global Hawk The Global Hawk Unmanned Aerial Vehicle provides Air Force and joint battlefield commanders near-real-time, high-resolution, intelligence, surveillance and reconnaissance imagery. In 2004, the Global Hawk provided Air Force and joint warfighting commanders more than 15,000 of these images to support Operation Enduring Freedom, flying more than 50 missions and 1,000 combat hours to date. Cruising at extremely high altitudes, Global Hawk can survey large geographic areas with pinpoint accuracy, to give military decision-makers the most current information about enemy location, resources and personnel. Once mission parameters are programmed into Global Hawk, the UAV can autonomously taxi, take off, fly, remain on station capturing imagery, return, and land. Ground-based operators monitor UAV health and status, and can change navigation and sensor plans during flight as

Figure 13: Global Hawk UAV

necessary. Global Hawk, which has a wingspan of 116 feet (35.3 meters) and is 44 feet (13.4 meters) long, can range as far as 12,000 nautical miles, at altitudes up to 65,000 feet (19,812 meters), flying at speeds approaching 340 knots (about 400 mph) for as long as 35 hours. During a typical mission, the aircraft can fly 1,200 miles to an area of interest and remain on station for 24 hours. Its cloud-penetrating, Synthetic Aperture Radar/Ground Moving Target Indicator, electro-optical and infrared sensors can image an area the size of Illinois (40,000 nautical square miles) in just 24 hours. Through satellite and ground systems, the imagery can be relayed in near-real-time to battlefield commanders [15].

Space Assets

DSCS

Space assets are vital in today's information-thirsty battlespace. These include communications systems, timing-spatial assets, and ISR platforms. Some that our notional battlespace may depend on are described next. The Defense Satellite Communications Systems (DSCS) consists of 13 Phase III satellites in geosynchronous orbit, operated by Air Force Space Command. Each satellite uses six super high frequency transponder channels capable of providing secure voice and high rate data communications. DSCS III also carries a single-

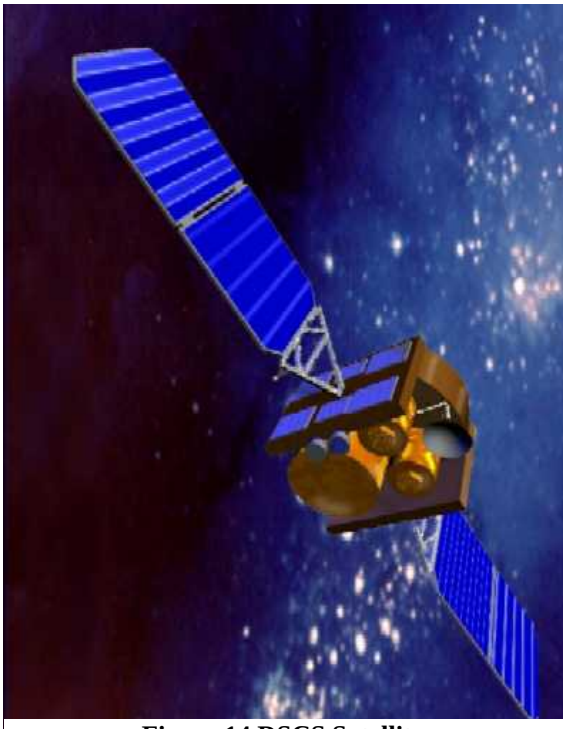


Figure 14 DSCS Satellite

channel transponder for disseminating emergency action and force direction messages to nuclear-capable forces. The system is used for high priority command and control communication such as the exchange of wartime information between defense officials and battlefield commanders. The military also uses DSCS to transmit space operations and early warning data to various systems and users.

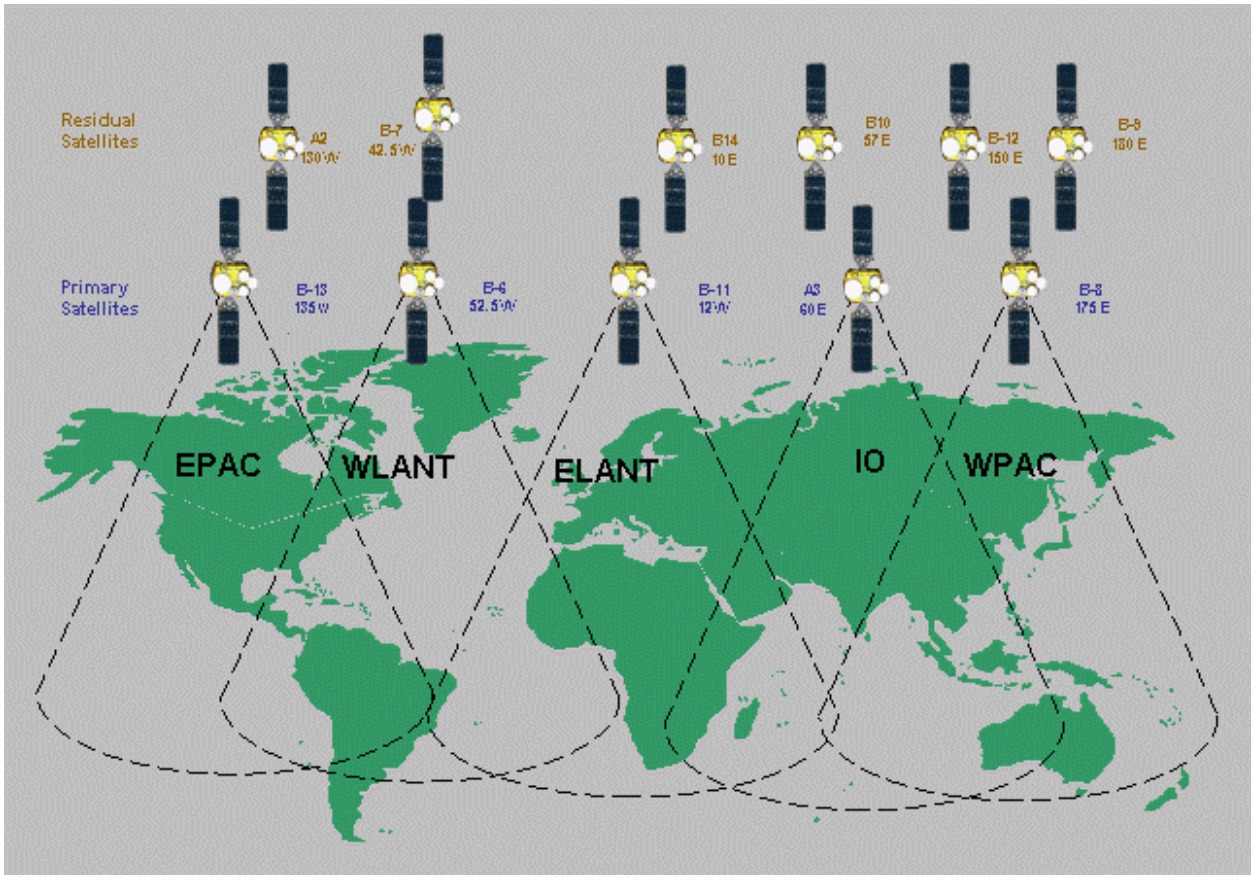


Figure 15 DSCS Overview [16]

First launched in 1982, DSCS has been the workhorse of military satellite communications. The system is built with single and multiple-beam antennas that provide more flexible coverage than its predecessor. The single steerable dish antenna provides an increased power spot beam which can be tailored to suit the needs of different size user terminals. DSCS III satellites can resist jamming and consistently

exceed their 10-year design life. DSCS users operate on the ground, at sea or in the air.

Primary Function: Worldwide, long-haul communications

Weight: 2,716 pounds (1,232 kilograms)

Power Plant: Solar arrays generating average of 1,500 watts

Orbit Altitude: 22,230 miles (35,887 kilometers)

Dimensions: Rectangular body is 6 feet long (1.8 meters), 6 feet high (1.8 meters), and 7 feet wide (2.1 meters); 38-foot span (11.5 meters) with solar arrays deployed

Unit Cost: $200 million [17]

GPS

The Global Positioning System is a constellation of orbiting satellites that provides navigation data to military and civilian users all over the world. GPS satellites orbit the earth every 12 hours, emitting continuous navigation signals. With the proper equipment, users can receive these signals to calculate time, location and velocity. The signals are so accurate, the system is used by computer networks and other systems to keep master station time and it has been found to keep time within a millionth of a second, velocity

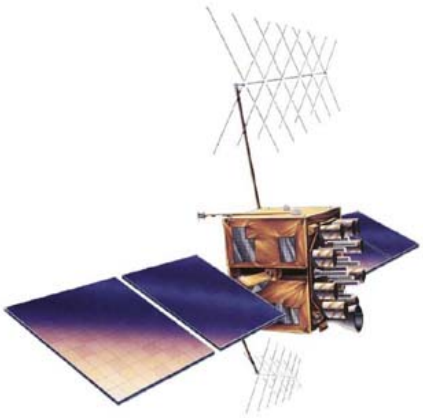


Figure 16: GPS Satellite

within a fraction of a mile per hour and location to within 100 feet. Receivers have been developed for use in aircraft, ships and land vehicles, as well as cell phone sized mobile units for individual use. GPS extremely accurate, three-dimensional location information (latitude, longitude and altitude), velocity and precise time on a worldwide common grid that is easily converted to any local grid, 24 hours a day in a passive, all-weather capability. The GPS constellation is designed and operated as a 24-satellite system, consisting of six planes, with at least four satellites per plane. The Delta II expendable launch vehicle is used to launch GPS satellites from Cape Canaveral Air Station, Fla., into nearly 11,000-mile circular orbits. While circling the earth, the systems transmit signals on two different L-band frequencies. Their design life is 7.5 years. The GPS-dedicated ground system consists of five monitor stations and four ground antennas located around the world. The monitor stations use GPS receivers to passively track the navigation signals on all satellites. Information from the monitor stations is then processed at the master control station and used to update the satellites' navigation messages.

The master control station crew sends updated navigation information to GPS satellites through ground antennas using an S-band signal. The ground antennas are also used to transmit commands to satellites and to receive state-of-health data (telemetry).

GPS capabilities were put to the test during the U.S. involvement in operations Desert Shield and Desert Storm. Allied troops relied heavily on GPS to navigate the featureless Arabian Desert. During operations Enduring Freedom, Noble Eagle and Iraqi Freedom, GPS contributions increased significantly. During OIF, the GPS satellite constellation

allowed the delivery of 5,500 GPS-guided Joint Direct Attack Munitions with pinpoint precision (to about 10 feet) and with minimal collateral damage. This was almost one-fourth of the total 29,199 bombs and missiles coalition forces released against Iraqi targets. GPS continues to fill a crucial role in air, ground or sea operations guiding countless service members and equipment to ensure they are on time and on target [18].

Milstar

Milstar is a joint service satellite communications system that provides secure, jam resistant, worldwide communications to meet essential wartime requirements for high priority military users. The multi-satellite constellation links command authorities with a

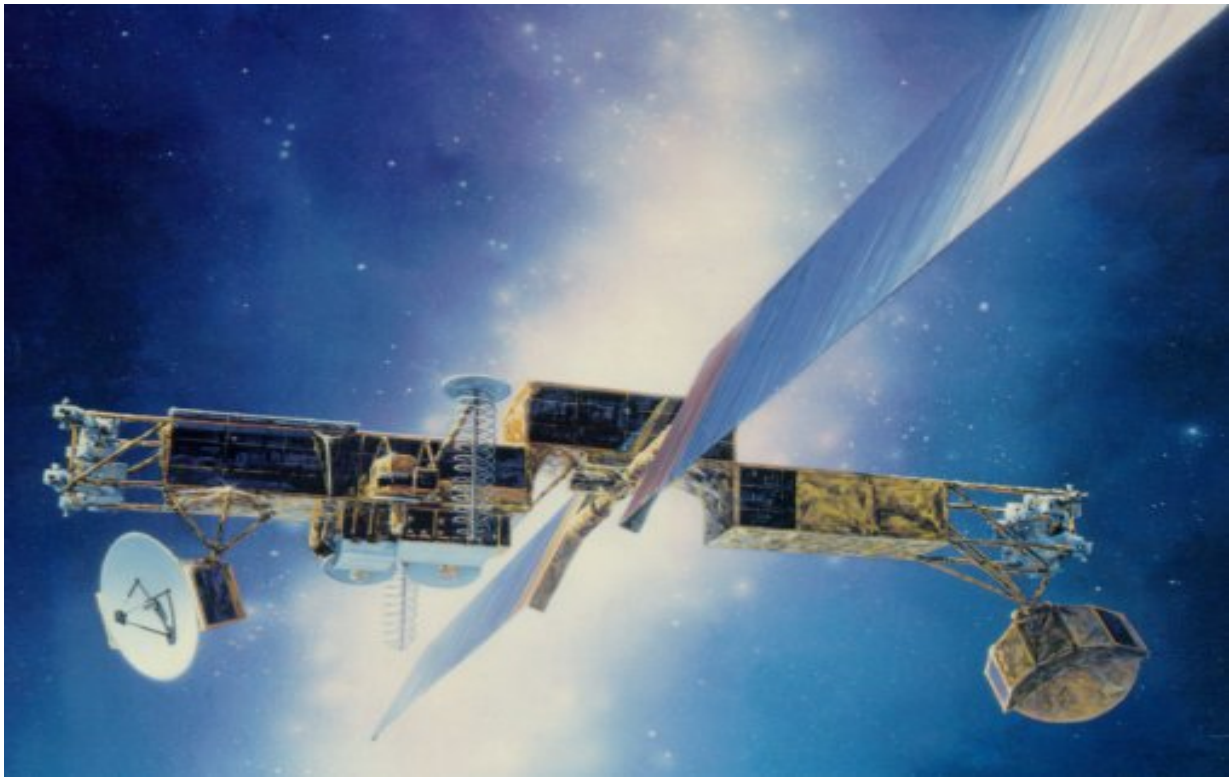


Figure 17: Milstar Satellite

wide variety of resources, including ships, submarines, aircraft and ground stations. Milstar is the most advanced military communications satellite system to date. The operational Milstar satellite constellation consists of five satellites positioned around the Earth in geosynchronous orbits. Each mid-latitude satellite weighs approximately 10,000 pounds (4,536 kilograms) and has a design life of 10 years. Each Milstar satellite serves as a smart switchboard in space by directing traffic from terminal to terminal anywhere on the Earth. Since the satellite actually processes the communications signal and can link with other Milstar satellites through cross links, the requirement for ground controlled switching is significantly reduced. The satellite establishes, maintains, reconfigures and disassembles required communications circuits as directed by the users. Milstar terminals provide encrypted voice, data, teletype or facsimile communications. A key goal of Milstar is to provide interoperable communications among the users of Army, Navy, and Air Force Milstar terminals.

The first Milstar satellite was launched Feb. 7, 1994 aboard a Titan IV expendable launch vehicle. The second was launched Nov. 5, 1995. The third launch on April 30, 1999, placed the satellite in a non-usable orbit. The fourth through six satellites have a greatly increased capacity because of an additional medium data rate payload and were launched on Feb. 27, 2001, Jan. 15, 2002, and April 8, 2003

Primary function: Global military communications system

Power plant: Solar panels generating 8,000 watts

Weight: About 10,000 pounds (4,536 kilograms)

Orbit altitude: 22,250 nautical miles (geosynchronous orbit)

Payload:

Low data rate communications (voice, data, teletype and facsimile) at 75 bps to 2,400) bps (All satellites)

Medium data rate communications (voice, data, teletype, facsimile) at 4.8 kbps to 1.544 bps (Satellites 4 through 6 only) [19]

A Notional Battlespace For Dynamic Wireless Network Simulation/Testing

This study defines a subset of assets and nodes that might be found in a notional battlespace. This notional battlespace – generic in concept, might be envisioned as the Area of Responsibility of an assigned Joint Task Force Commander (JFC).

More and more assets found in a theater of battle are connected via multiple communications systems. Some use legacy systems while others harness new technology and use innovative mediums. Some of these systems are stationary or placed in relatively stationary positions and can be relied upon for use by other systems. Today, many of the connections needed between assets are planned in advance, require cabling or engineered antenna placement to gain the desired fixed, line-of-sight connection. For the US armed forces, many of these stationary connections are designed well in advance of the conflict, involve moving tons of mobile combat communications equipment into the theater of operations, and take time to setup/build-out. These same connections will remain in-place as the gateway to the internet and the reach-back capability our information systems require to support the conflict. A growing trend in military operations is to use contracted services in the

theater of conflict. These again are stationary communication stations with planned and very predictable connectivity and link-state. A very lucrative research area that may in the future reduce the air and sea lift required for US military operation is dynamic wireless network architectures. The proposed notional battlespace includes a description of current communications and connectivity requirements as well as some consideration given to some of these future concepts being introduced to the battlespace.

In the near-term military application, dynamic wireless networks will not operate in isolation and will likely deploy/exist in areas where some number of stationary assets are located. Stationary assets will arrive to the battlefield in much the same way they do now or will be organic to the battlespace. This limited number of fixed nodes will be used as robust reach-back to rear echelon assets and to the homeland based forces. They will likely be huge connectivity pipes, assuming future growth and development of common long-haul data links. They will also likely be border routers and bridges to the internet for dynamic networks that operate throughout the battlespace and point back to the “border” or “trunks” for connectivity to other dynamic networks, the internet in general and reach-back to rear echelon forces. In a number of research papers, dynamic or ad hoc wireless network connection algorithms rely on one or more “master” nodes that issue internet protocol addresses, act as a bridge between networks, keep link information on next hop toward internet/external network connections. These limited numbers of stationary nodes would be used to perform this

role in the notional battlespace and could be described and listed in the network tasking order and provided to routing nodes as link-state information.

Other assets in the battlespace use and will continue to use point-to-point RF connectivity as the medium of choice for voice and data communications functions. Many of these will remain unchanged in process and execution, however, through better understanding of the voice/data requirements, more efficient transmission algorithms and perhaps advances in RF technology, there may be additional capacity that could be used by the dynamic wireless network system to forward data in a target of opportunity, connection-less, basis.

Mini Scenario: By this we mean for instance, a ground unit has a data set of X bits that needs to be transmitted to the Joint Operations Center (JOC) located in the rear echelon. This data set has been identified as a bono fide need in the network tasking order and has been assigned as a low priority need, and the data set has a 24 hour shelf-life (information is useable up to 24 hours after collected). For example, this data might the previous day's stores or miscellaneous supplies consumption rate. If this data isn't sent within 24 hours, the next day's data is sent instead (because it will more current).

During the day, an aircraft with excess bandwidth capacity passes within Line of Sight (LOS) of the ground unit and during the 6 minutes the aircraft is within view of the unit, the passive dynamic wireless network system synchronized, authenticated, established a path to the JOC; accepted the data set, exchanged required acknowledgements and confirmations and transmitted additional low-priority data sets that had been queued

for that unit and then broke off link connectivity when the bit error rate reached an established maximum threshold.

Network Tasking Order

This paper specifically lays out the ground work for a notional battlespace for use in future research. The various communications assets/nodes that are in the battlespace and might be used to route dynamic traffic could be spelled out in a network tasking order that captures the expected location of mobile nodes and their predicted movement throughout the period of the order. This information would not have to be precise, but could be used by routing nodes to predict when and where links might be established and use data from the network tasking order to determine the capacity of those links when connected, and make decisions about when and how to route the dynamic traffic to/through them. The network tasking order does not exist today. And, although much information is available about nodes, capacities and required bandwidth, the author is not aware of, any comprehensive document or database that might provide all the data required for this effort. It will be necessary to develop a network tasking order to capture sufficient data to provide the dynamic network routers a basis for making predictive decisions about where given nodes are spatially in a battlespace, what data links might be available, the bandwidth or throughput of such links, the bandwidth requirements of various data flows, and the priority of the data that might be destined to or coming from various nodes. While this network tasking order does not exist today in a format that might be useful to a master node in a dynamic network, most of the needed information is available in one form or another, and creating this

electronically collaborative effort could merely involve gathering the data into a single, useable source (database, interactive web application, etc.). An additional benefit of collecting this data into a single source would be to provide senior leadership – both communications and signal corps type leaders and operational leaders – a single source to determine impact when assets and links are down. In the South West Asia Area of Responsibility, a Communications Tasking Order (CTO) is used to provide some of this information in a single document. While the current communications tasking order provides some of this data, it does not go far enough to enumerate and prioritize each unit's data and information needs (how much bandwidth for what applications where and when). We have a good understanding of overall communication needs, but not specific requirements for each unit. Having a better resolution and more details into specific data needs and real priorities will help usher in a more efficient use of theater bandwidth and enable better collaboration. This raises the question of what sources are available today to use as resources for putting together a network tasking order.

Network Predictability: Predicting Node Location and State

The US military today relies upon point-to-point, established communications links to move information and data into, within and out of a given battlespace. This network of communications links includes traditional terrestrial and satellite waveforms, including all forms of RF analog and digital communications, copper and fiber cable connectivity and the associated hardware to multiplex, modulate, transmit, receive, demodulate, demultiplex and move data. The links are established as units move into the battlespace and are defined and described in an electronic forum called the CTO.

Current Networks

As stated before, most of the networks are RF and the backbone links are stationary networks installed to move data between and among units and the rear echelon or Headquarters. While many of these nodes are mobile, their connectivity is point to point based, most of which have one point stationary (anchored) and the mobile side of the connection relying on the stationary unit to provide the reach-back connectivity to units the mobile side cannot directly (line of sight) connect with. This current method is fairly robust and might be modeled as shown below.

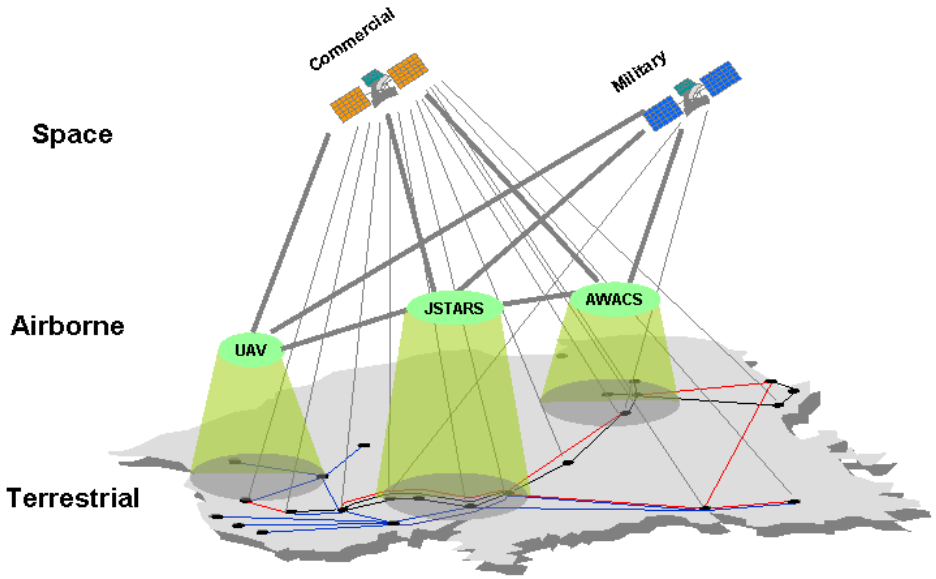


Figure 18: Representation of Battlespace Communication Links [20]

Each of the aircraft are mobile, but the satellites and most of the ground nodes are relatively stationary. Further, many of these links are point to point and dedicated for links between those entities. This might be shown in two dimensions in this manner, where stationary assets/nodes and mobile nodes are shown as circles for RF coverage area, lines to represent dedicated links. Most of these nodes are stationary, and mobile units connect to the stationary units directly (dedicated) to gain access to overall network and thereby are able to talk to other nodes not within their RF coverage area. In a future dynamic network, the coverage circles may be the same, but rather than having dedicated links between nodes, the routers would determine the best path between sender and receiver that is available at this moment, given that the nodes are all moving. The relatively few stationary nodes might be the Brigade Tactical Operations Center, the Joint Operations Center, and the satellites used for communications coverage. All other links will be established between mobile units and will be active only as long as the units are within reach of each other and only as needed for data flow.

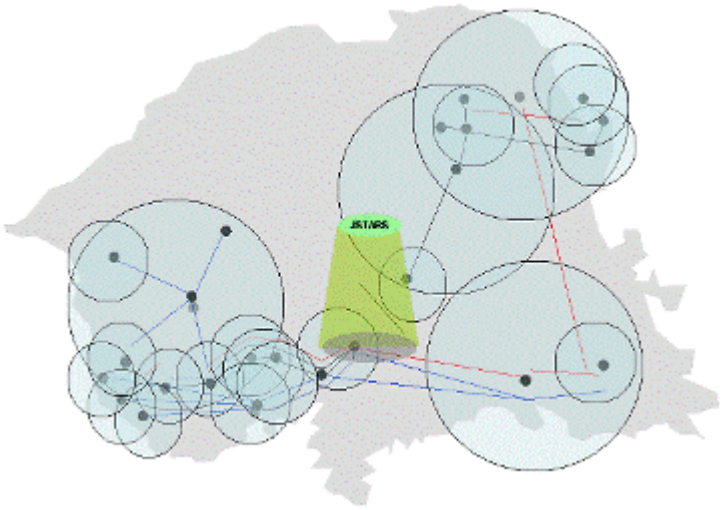


Figure 19: Two Dimensional RF Coverage

Dynamic Wireless Network

In the future, more of this backbone connectivity will be moving to a dynamic network model. There will still be traditional stationary nodes, but they will be fewer and they

will be the exception, rather than the rule. Dynamic networks refer to multiple parties moving and still being able to synchronize and communicate, but not necessarily with the same node each time. Consider a cellular telephone network. As the vehicle travels along the road, the radios in the cell tower are providing connectivity with the cell phone used in the vehicle. The radios in the cell tower and the phone, sense and connect with cell phone anywhere within its propagation coverage area (represented by a circle in the figure below). When the cell phone is mobile within that area of coverage, the equipment within the tower may hand off the phone call between radios, it is still being serviced by the specific tower. When the phone moves from one tower's coverage to the next, the compatible cell tower systems will handoff the phone call while cell tower systems that are not compatible may drop the call. While one part of this connectivity link is mobile, this example would not be considered dynamic – it's more of a traditional radio link – one side of the connectivity is stationary and the other roams, but knows (or the operator knows) where to point for connectivity.

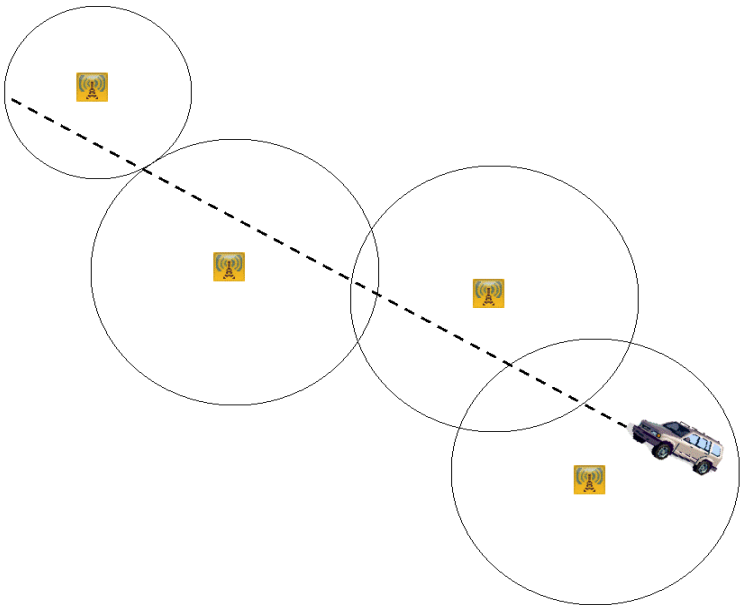


Figure 20: Cell Phone Tower Coverage

For a dynamic network, consider the citizens band (CB) radio. The radio and technology is not dynamic, but reliably getting a message across a long distance using

CB radio, relies upon a dynamic network of radio enthusiasts passing the message say, from San Mateo County in California to Stafford County Virginia. The hundreds of individual links in the path would simply be point-to-point radio traffic. What makes this example dynamic is that truck drivers, hobbyists and others across the nation have to agree to pass the message, do it via a variety of the 40 channels that make up the CB spectrum and the sender/receiver are counting on the individual intermediary stations to receive and pass the correct message on. Getting back to a battlespace, consider most of the nodes moving (being mobile), each one having a variety of communications equipment (similar to the variety of CB channels), with a variety of bandwidth capacities and a variety of bandwidth requirements. In this scenario, a node may have a low bandwidth radio capability; a higher bandwidth SATCOM capability and a high bandwidth receive capability from a global broadcast system receiver. As nodes move within coverage areas of each other, the dynamic network routers would be tasked to sense the link capability, determine the available bandwidth, the data priority and establish the appropriate connection all within what may be a small amount of time the two nodes are within the joint coverage area.

In the CB example, where a message is to be relayed across the country via CB radio, it would be virtually impossible to predict or direct the exact path of that message as it is passed from truckers and hobbyists to reach the destination. Yet, we could know for instance that the path will likely follow major highways. We may also be able to determine which truck companies or types of drivers still use CB radios vice cell phones for communications. Each data point would give us some predictability into our

message path. In the Battlespace scenario, it is difficult to know when mobile nodes would pass into each other's communications coverage zones. Terrain, weather, enemy forces and other factors can make even known stationary nodes difficult to connect with. However, we can gather some information about known locations of mobile assets/nodes, about known node movements for a given period of time, as well as knowing what communications and connectivity capability each node has and the stated required bandwidth needed by that node to meet the given mission tasking. Information about unit/node location is gathered today in a number of different formats for a number of different reasons. In the future when dynamic networks are more common, it would seem reasonable that the network would have some degree of predictability to improve the probability of connections among nodes and improve the reliability of data and information flow within the battlespace. Therefore, the information in the current communications tasking order can be augmented with the data from these other sources to provide a more complete picture of where nodes are and where they are scheduled to be in the next few to 24 hours. Fusing this information together, taking the relevant node location/capacity data and sending it out to the dynamic routers within the battlespace will enable link-state prediction and reduce the uncertainty/unknown/entropy of the overall system. If this were not so, the technology could not be employed for information/data-demanding US forces.

Sources of Location Information

Communications Tasking Order (CTO).

The current CTO allocates the useable electromagnetic spectrum to the various units in the AOR, prescribes networks and provides contact information for each network manager. The document lists various data links, describes their capacity, maintenance actions, and provides the senior communicators in the AOR – usually the "J-6" with up-to-the-minute availability and downtime visibility. This electronic document is used by field units as a guide for installing new circuits, giving information for troubleshooting end-to-end problems and giving the lower-echelon communication and signal corps personnel a broader picture of the overall battlespace network.

Three other existing systems lend themselves to this providing data needed to provide some predictability of node location within a battlespace. They are the Air Tasking Order, the Common Operating Picture, and Blue Force Tracking. There are many other systems in use today by the US armed forces to track location of personnel, logistics, warfighting assets, etc. We'll focus on these three systems and leave other systems to be applied in similar manner.

Air Tasking Order

The Air Tasking Order or ATO is defined in Department of Defense doctrine as a method used to task and disseminate to components, subordinate units, and command and control agencies projected sorties, capabilities and/or forces to targets and specific missions. The ATO normally provides specific instructions to include call signs, targets, controlling agencies, etc., as well as general instructions [21]. As a brief explanation, the Joint Forces Air Component Commander (JFACC) uses the air tasking cycle that

produces the ATO as the overarching process to manage the air tasking for an air campaign. The process is repetitive and the ATO typically describes/prescribes the air action for a period of 24 hours. At any one time there are three ATOs present in the air tasking cycle. There is the ATO in planning, the ATO in execution and the ATO in assessment. One could consider the ATO life cycle to be roughly 72 hours. The ATO in planning is tomorrow's air battle plan. The ATO in execution is today's and the ATO in assessment was yesterday's and the assessment is determining the effect of that battle plan, the battle damage and determining the need to readdress some of those targets [22]. The ATO is a joint document and there are hundreds of pages of research, doctrine and operational directives on how and why the ATO is produced. For this research it is sufficient to say the ATO spells out what tracks (elliptical paths flown by orbiting aircraft) are to be used by refueling and ISR assets, describe flight missions/paths for nearly every aircraft in the battlespace as well as providing targeting, COMSEC and other critical information to Airmen throughout the theater. From the ATO, the network can be fed predictive information about where mobile nodes (aircraft) are expected to be and from the data determine when they should be there and when the nodes might be within coverage areas of other nodes. As an example, the refueling track or anchor is an elliptical orbit the aircraft flies and by designating which anchor point and where it is, other aircraft know where to go to get fuel once in the air. If that tanker were equipped with a dynamic network access point of some kind, it might be within Line-of-Sight (LOS) of a ground unit during part of the orbit and may be able to pass data to rear echelon for that unit. The tracks or anchors are usually 4 nautical

miles (NM) either side of a centerline and the track length is normally between 50 and 100 NMs in the US [23]. (This description of tracks/anchors may vary in combat situations). If routers in the dynamic network know where they are (through GPS, for instance) and are given the predicted state for other nodes, such as the air refueler's track/anchor, the router may be able to use this predicted state information to improve the probability of connection and data flow.

Common Operating Picture

A second system that may be able to provide data to the dynamic network's predicted link-state is a link to the Common Operating Picture. Currently, joint doctrine defines the COP as "a single identical display of relevant information shared by more than one command. A common operational picture facilitates collaborative planning and assists all echelons to achieve situational awareness." [24] In the future, the transformational COP envisioned by the Secretary of Defense and Joint Chiefs of Staff is not only a box that fuses all information across the spectrum of warfighting—from time-critical targeting (TCT --now called Time Sensitive Targeting (TST)), to intelligence, surveillance, and reconnaissance (ISR), to fused, real-time information flow—but also a process that ties it all together into a complete, total command and control system for the warfighter that is part of the JTF system and structure [25:3]. Unfortunately, the "Common Operating Picture" isn't as common as it could be and will be in the future. Today there are several common operating pictures. There is one in the Joint Operations Center that is fed from various sources in the battlespace and at least one version of it runs on the Global Command and Control System operated by the Defense

Information Systems Agency (DISA). There is another one currently running on the Theater Battle Management Core Systems in the Air Operations Center and the current documentation suggests another one operating as part of the Force XXI Battle Command, Brigade and Below (FBCB2) system within the Stryker BCT. Some of the data is common among all systems and Joint Visions 2020 calls for it to be common among all in the near future. For this research effort, it is important to note the existence of the common operating picture and plan for appropriate operational interfaces that will enable the network to gather node location and link-state from the information already being collected for critical decision makers. If the data is being collected and is relatively accurate, the node location data might be usable to the dynamic network routers for use in predicting nodes moving within coverage of each other and predicting link-state connectivity.

Blue Force Tracking

One final source for pre-determining node location would tie into another system of systems used today. This collection of disparate systems is used for Blue Force Tracking. Blue Force Tracking is done by a number of systems that have the same goal in mind: Determine and track where friendly forces are and use this information to prevent tragic friendly fire incidents. Today, US armed forces are using at least four different systems to do this; one for aircraft, Army FBCB2 uses another one, Special Operations Forces (SOF) uses a similar system, and finally certain Marine units are using yet another system. Unfortunately, each of these systems are a little different, requiring a gateway or human intervention to make the data interoperable within a

battlespace. This particular application umbrella is entertaining a number of research topics in battle labs and research institutions across the nation.

This paper will describe how one system works. After an incident in the Balkans where three soldiers were captured by the enemy, the Army implemented a special application built around Qualcomm Inc's OmniTRACS system, a commercial vehicle tracking system used by hundreds of companies throughout the world to track vehicles and cargo shipments [26]. The basis of the Army's system is a modified version of the commercial product and designed to directly interface with the FBCB2 command and data console. The system includes a mini SATCOM radio and antenna, an interface to the unit's GPS unit and an interface to the FBCB2 computer system. The FBCB2 computer system consists of a rugged notebook with a touch-screen and keyboard mounted in a vehicle. The Blue Force Tracking system is tied to the FBCB2's GPS and polls and sends the vehicle's position, direction, speed and other parameters to a central location every 5 minutes. The system also offers text messaging which follows the same path. As part of the Army implementation of the system, it can use either terrestrial RF or SATCOM to communicate the vehicle's position. A special micro router was developed for the system to enable automatic switching between Ku and L band SATCOM as well as terrestrial communications systems [27]. At key vehicles within the platoon, company, battalion and brigade, this position information is collected and displayed on the FBCB2's Common Operating Picture, giving leaders at all levels information about friendly

Figure 21: Satellite Tracking Equipment

personnel location. The Army field manuals and operating procedures warn all leaders to use this information as a tool, but not to rely exclusively on the data when determining firing solutions, primarily due to the delay in updates (5 minute default refresh interval). Nonetheless, this application provides timely and relatively accurate data about where personnel and assets are located in the battlespace. This information is not only consumed within the brigade but in current Iraqi operations, it is forwarded to all command/leadership levels from base/camp commanders to the Joint Forces Land Component Commander and the Joint Operations Center. Again, given the availability of the data, this information could be used to provide node state information at the beginning of the day (following the ATO format) with periodic updates as often as practical for the dynamic routers to use to predict where nodes with additional and accessible capacity might be located and when other mobile nodes might converge in RF coverage area.

A hypothetical future scenario to be used to study dynamic wireless networks

The following scenario will be used to illustrate this point and provide a reference point for the remainder of this work. This scenario will be used in various follow-on research simulations.

A small US task force has been organized and deployed to secure a province in Elbonia [28], a small sub-Sahara, US-friendly, oil producing nation struggling with local corruption, tribal tyrants and growing unrest. Recently, international terrorist organizations have built training camps in the rogue province. Two of the camps appear to be functioning headquarters for the organizations, according to US analysts.

Official Elbonia leadership denies any involvement with international terrorism, but sees the opportunity to rid themselves of future political opponents as well as garner additional US aid. They have requested assistance from the US armed forces to help eliminate the terrorist organizations from their country. A task force was organized and deployment coordinated with the host nation. Neighboring countries on three sides of Elbonia are fanatical in their beliefs and practices and oppose US presence in the area. Intelligence and State department officials suspect other large nations are using these neighboring countries to actively pursue signal, communications and other forms of intelligence gathering against the US and US allies. All US task force communications are encrypted and must be routed through the US-established, trusted gateway to ensure maximum COMSEC and OPSEC.

While Elbonia is small, the borders are soft and not well defined. Further, the tribal warlords and their armies freely cross designated borders in and out of these neighboring countries and are enjoying a good deal of freedom of movement. The US administration determined early that these borders would not be considered a constraint unless neighboring countries 1) formally protest to the UN Security Council and 2) placed standing armies on the borders. Therefore, the AOR or battlespace for this scenario is roughly 400 square-miles.

The committed US forces include one Stryker Brigade Combat Team, one squadron of F-16s to address any air interdiction requirements and a squadron of A-10s to provide

close air support to the ground forces. The Joint Task Force Commander (JTF/CC) ordered two UAVs (Predators) to provide surveillance and one additional high-altitude UAV for extended communications capabilities. The UAV's video capability was demanded not only for the combatant commanders to use in their decision making process, but also to meet the Administration's requirement for near-real-time video feedback to the US, for top-level oversight. Recognizing the huge bandwidth requirements of the UAVs, a high-altitude communications relay type UAV (Global hawk) was added to the mission portfolio to provide this vital data link. Therefore there are three UAVs -- two Predators and one Global hawk).

Additional assets in the AOR (but not necessarily dedicated to the JTF mission) include one Airborne Warning and Control aircraft (AWACS) one Joint (JSTARS) and one tanker (KC 135 or KC-10 depending on the mission and day). These assets are used in other missions and are available when needed and called for in the Air Tasking Order. Their orbit, location and communications capabilities vary and will be detailed in the Air Tasking Order and from that, the location information will be integrated into the Network Tasking Order for network planning purposes.

Simplifying the Notional Battlespace

In an effort to support the general research associated with this topic, it is necessary to simplify the number of assets in the experimental battlespace. There are literally thousands of possible connections or links in a real battlespace, and in researching,

experimenting and testing dynamic link algorithms and other connection variables it is imperative we start with a fixed, controlled set.

From the above described “small” scenario, the number of assets under the control of the JTF/CC are a Stryker Brigade Combat Team, roughly 3500 men, 300 Stryker vehicles, and 50 C-17 equivalent loads associated equipment. A squadron of A-10s and F-16s is 16 to 24 aircraft each, with a maintenance and logistics requirement that could easily equate to 600 personnel and associated equipment. The other air assets, though not dedicated, add yet more data and connectivity requirements. This scenario provides hundreds of nodes that require various types of connectivity with various capacities to meet the JFC’s mission requirements. Adapting a Link 16 (one specific tactical data link program with the primary mission of sharing information amongst a small subset of the battlespace community) Program Office slide, this scenario and some of the hundreds of connections could be represented in the next chart

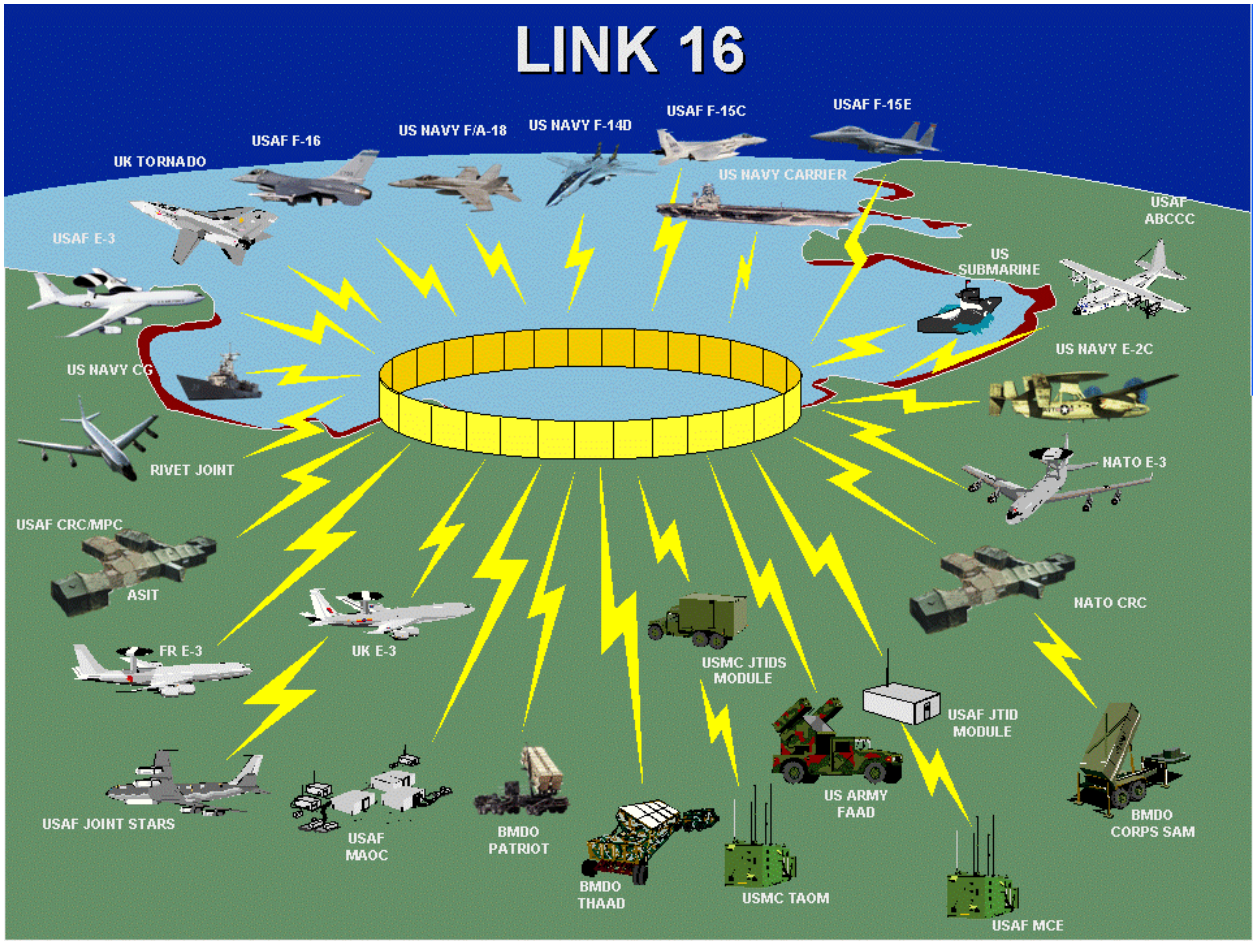


Figure 22: Tactical Data Link 16 Representation [29]

This scenario is too large to model as a whole. Hence, this scenario will be reduced to the following representative scenario. In an effort to create a controlled number of communication links, routing options and assets with which to test and experiment with, this paper will consider the above described scenario, supposing only the following assets to be available for a given day: One Stryker Rifle Platoon (43 men and 4 ground mobile assets),

- One Stryker Battalion Tactical Operations Center (TOC)
- One two-ship interdiction package (2 F-16s)

- One two-ship CAS package (2 A-10s)
- Two surveillance UAVs (not organic to Stryker – operated by AF [*])
- One High Altitude UAV flying communications relay package. (Fictional asset may be based on a Global Star UAV platform.)
- One ISR platform (Joint STARS or AWACS)

This equates to roughly 20-45 network nodes (depending on resources available) and should provide a robust example to use in initial and early simulations and tests of the protocols and algorithms being developed during this overall research effort.

Though these assets are all in use today with traditional voice/data networks, we will assume some type of communications medium technology has been developed and introduced to make some of the communications capability interoperable with, if not completely reliant on dynamic wireless network principles. We will assume the link capacity stated for each system and that these dynamic links are in addition to other traditional networks on board some of these legacy warfighting assets. We will also assume the estimated data traffic loads – inbound and outbound, represent the data that is to be transmitted/received via the IP-based dynamic wireless network, perhaps utilizing traditional links.

Assumptions:

- Assets in the notional battlespace have adopted a dynamic wireless network topology, methodology and algorithm.

[*] Additional UAV flown by AF controllers because author of this paper cannot find any information about flight, control, data or connectivity requirements of he Stryker BCT's embedded UAVs.

- Data will be for each entity listed above and will assume entities are single objects. For instance, the Stryker platoon will be considered one unit, although there are actually four vehicles. The A-10 two-ship, will be considered a single unit and communications to and from the two-ship formation will be modeled as a single link.
- The link capacities, notional output and inbound traffic represent the data and information flow that has been designated to flow in the dynamic network.
- Other connectivity may be available to the operators of the assets that is not reflected in the Data Flow Matrix at Appendix A. This connectivity and the data and information flows that might use those connections will be considered outside the scope of this research. An example might be air to ground air traffic control communications stays on traditional RF vice dynamic network.
- The data is assumed to follow a Poisson arrival distribution with an exponential distribution for service times based on the random nature of the communications being modeled. How such traffic, moved from traditional communications links to an IP routed dynamic network will behave is an area worthy of further research.

Looking at the Stryker Platoon – with the Stryker network having five different subnets, data being integrated and shared within the FBCB2 system and the constant update of location and vehicle telemetry, there are a number of connections and required paths to support the battalion. Further, during an actual or planned engagement, the platoon

could be in contact with the A-10s providing their Close Air Support/Fires role, the Joint STARS coordinating the action and receiving ISR feeds to keep their situational awareness current. The possible incoming data feeds to support this scenario are roughly graphed in the next chart. Dashed lines represent lower probability connections – ones that will not happen as often as the solid lines.

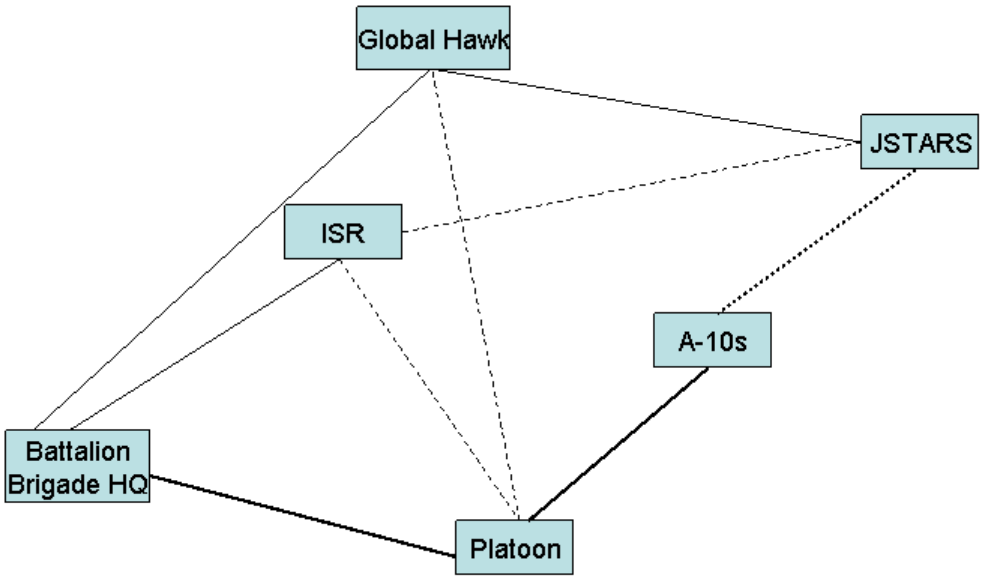


Figure 23: Possible Data Routes

The inbound link from the battalion Tactical Operations Center (TOC), brigade TOC and higher echelon (such as the Joint Operations Center), could be modeled as shown below where the three sources combine to become the stream of traffic bound for the platoon:

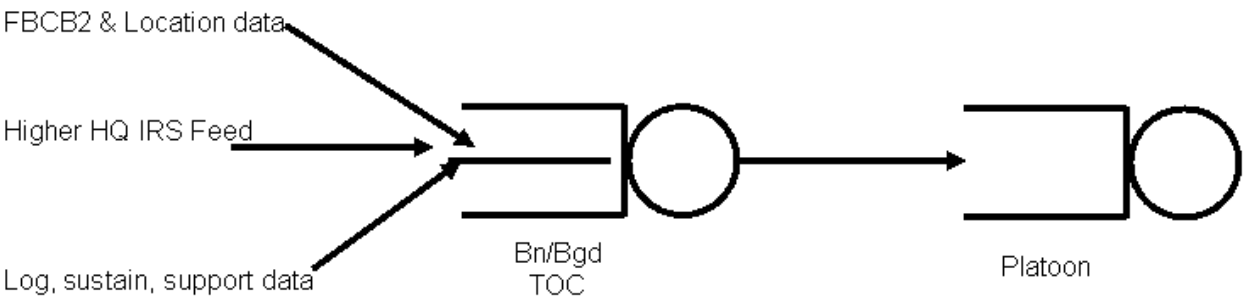


Figure 24: Input stream for data destined for platoon

There is a small part of the aggregate data flowing amongst the FBCB2 system that is relatively deterministic. Location data is set to transmit from each vehicle at set time intervals. This data might be 10 kbps average rate when the unit is engaged in routine operations. This data is sent from each unit every 5 minutes. This will be set to occur more often in the battlespace, e.g., every 2 minutes. All four platoon vehicles report this data every two minutes. The aggregate leaving from platoon to battalion and higher HQ is going to be 100 kbps every two minutes and the inbound similar traffic will be the collective data from all vehicles in the battalion. C2 vehicles within the Stryker BCT receive all the updates from all vehicles.

Other data on the FBCB2 system will be much more random and will tend to be bursty when the unit is engaged in training or actual combat/maneuvers.

ISR data to and from the platoon level unit is relatively limited, while the data could be considered nearly a constant stream going into the battalion/brigade TOC. Pertinent ISR data can be pushed to the platoon from the higher HQ and through the global broadcast system and could be received from ISR sources as needed.

Contacting aircraft is fairly routine and currently done mostly with voice channels. The platoon would talk directly to the aircraft providing supporting fires or close air support

to ensure the enemy is engaged in the appropriate locations and to prevent friendly fire incidents. The blue force tracking information is relayed over RF now and in the future could be relayed over both broadcast RF and repeated over the dynamic network, but perhaps augmented with additional information inappropriate for broadcast distribution, but for specific needs of the A-10 formation or Joint STARS for better situational awareness and targeting. This data flow could average relatively low packets per second and jump to much higher data flow levels when the unit comes in contact with the enemy.

Defining the actual data flow in the battlespace will take a great deal of additional research to review the data required by each unit and their sub-components. This research effort will be critical to the actual development of a network tasking order if it is to be a product usable by dynamic network routers to anticipate links being available and deciding if/when those links are the best path to complete the connectivity required. This effort will require additional resources and time to accomplish. For this paper, we will assume the outbound data listed in the Data Flow Matrix (Appendix A) represents the data each node is producing and the data rate required to move that data. Further to the right of the printed matrix, the destination of the data is checked. The load for each node was developed based on the papers, field manuals, fact sheets and briefings the author has already cited. Unclassified data and data flow rates are rare, hence fictional numbers are inserted and actual numbers are left for future work.

In the Data Flow Matrix (Appendix A), data flow is shown for the Stryker platoon as being FBCB2 System data, which is the data exchanged between battalion, brigade and higher units on the FBCB2 system including text messaging, location and vehicle status. Targeting data represents the updates the platoon would send to the fires support elements including any aircraft providing close air support. Collaboration might be anything not covered in the previous data links, including combat vehicle and force routing and maneuver coordination, supplies delivery/rendezvous, etc. Blue Force Tracking is listed separate from FBCB2 because the papers and field manuals suggest the system may feed FBCB2, but also operate separate from FBCB2. This supports the ability to send Blue Force Tracking to aircraft and control platforms that may not have FBCB2 on board.

Assumed communications capabilities and capacities are listed in the Communications Capacity Matrix (Appendix B). These are assumed because these units are not currently relying on dynamic networks for this data flow. We will assume some of the RF systems in place will be the connectivity for the future dynamic network and I have chosen to model bandwidth capacity after some of these systems. The capabilities and capacities are not all inclusive. Air to air radio communications, intra and inter-squad, platoon and company radio nets are likely to be used well into the future as primary voice communications. This capacity matrix is only intended to represent a small defined quantity of the capacity of the communications equipment that we will assume is excess capacity and available for use or even dedicated for use by the dynamic

network infrastructure. It is also assumed data flow requirements not addressed in Appendix A or B are outside the scope of this "notional battlespace" and connectivity is provided through traditional means. SATCOM capability is highlighted in the background portion of this paper and is available for use in the battlespace by those units identified in the Communications Capability and Capacity Matrix as having that ability. Further, we'll assume the Global Hawk air frame has been equipped with RF gear that can receive and retransmit signals in the same bandwidth as the satellite communications (but different frequencies) and the simulation and tests in the future can model this node as being either a bent pipe or smart node.

Network Tasking Order

Though not laid out in explicit terms, a future network tasking order may be used to provide data to aid dynamic network routing by feeding unit/asset communications and connectivity requirements, communications capabilities and capacity as well as the unit's location and forecasted movements. This information taken in whole could be leveraged by routing algorithms to improve the reliability and throughput of data in the battlespace. The network tasking order will be an electronic data collection containing a matrix of each unit's required data, forecasted surge data, and communications link types the unit can support. The data transfer can be modeled and the best routing for each moment can be found and used to provide the best throughput based on the interaction of the whole collection of mobile units.

Battle Rhythm Products

In an attempt to provide a useful document and tool to fellow researchers attempting to tackle the dynamic wireless network in the military battlespace, a notional battle rhythm for a day in the notional battlespace was developed. The notional battle rhythm matrix (Appendix C) provides a gross level outline of the major planned events in the described battlespace. The small quantity of units are described in terms of initial location, when and where they are scheduled to be throughout the day and where they are expected to be at the end of the day. These data points could be determined in advance each day using an effort similar to the aforementioned ATO process. The data could be drawn from the ATO and ground battle plans and used within the dynamic network architecture to anticipate when and where additional communications capability will be and plan to use the bandwidth in the most efficient manner.

Appendix D provides a graphic representation of the notional battle rhythm. Each page represents a different hour of the day (as marked) and units and icons are shown in relation to the grid overly of Elbonia. The ground units are scheduled to make a small movement during the course of the day, aircraft are flying into and out of airspace over the top of the ground units and heavy aircraft and ISR platforms are flying tracks or orbits in and around the area. All of this data could be used to develop a simulation of mobile assets that could be used to robust the dynamic network.

Data may be routed any number of opportunistic ways based on the available communications capacity and connectivity. Connectivity will depend on the proximity of nodes, the capacity of the communications equipment and the path the data needs to

take to get to its destination. For instance, in Figure 25, Joint STARS is passing targeting data via a high bandwidth channel, the platoon could be coordinating fires support on UHF with the A-10 and the UAV can provide real-time surveillance data via SATCOM to the JOC.

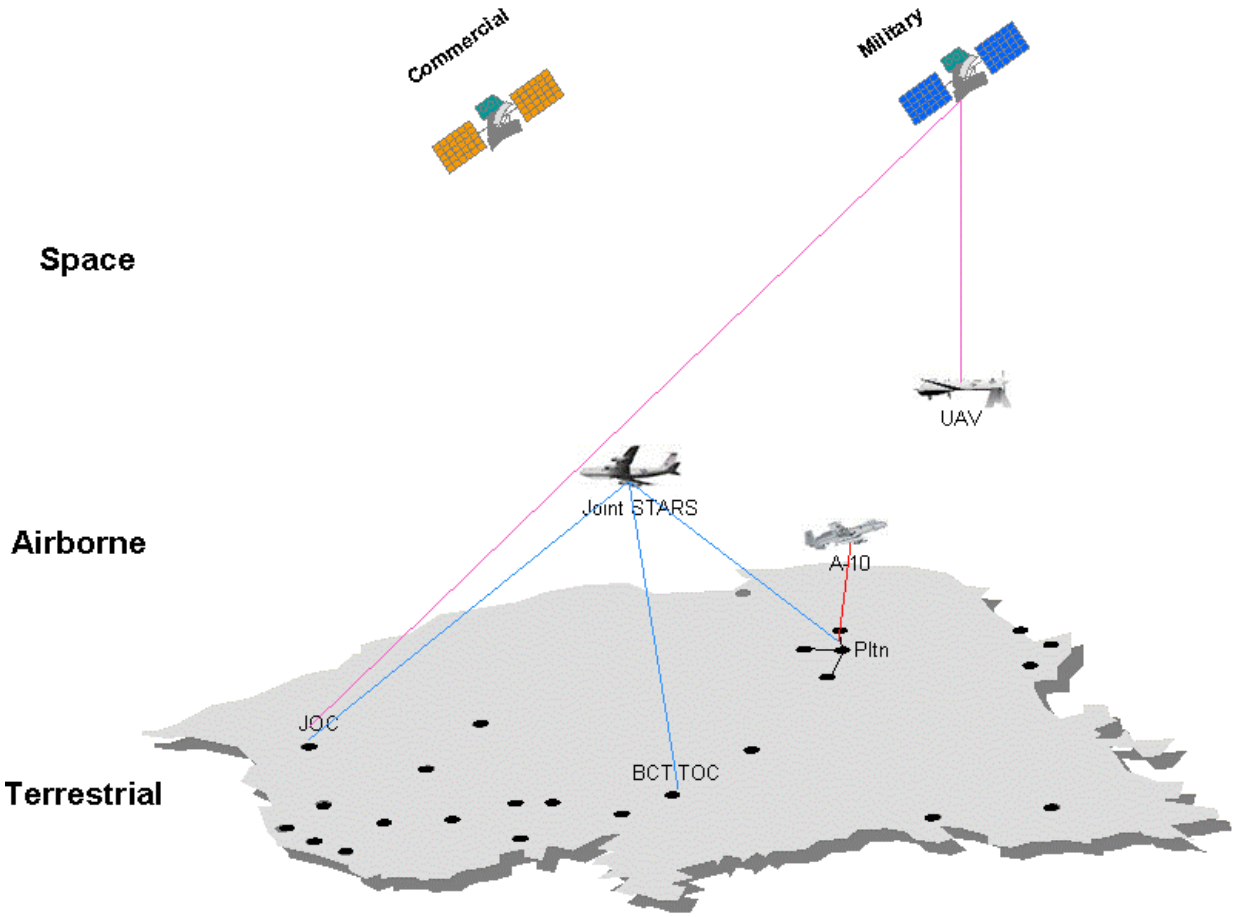


Figure 25: Possible Connectivity 1.

Suppose at the moment the JOC had critical information for the Platoon, the ground unit was out of line of sight for either the A-10s or the Joint STARS. The data might be routed via high altitude UAV communications relay to the JOC. Similarly, perhaps the Platoon needed to get a message back to their home station in the continental US. At

that moment, the Joint STARS has LOS and the capacity to help push the traffic, from the lower bandwidth VHF radio, convert it and send it over military SATCOM.

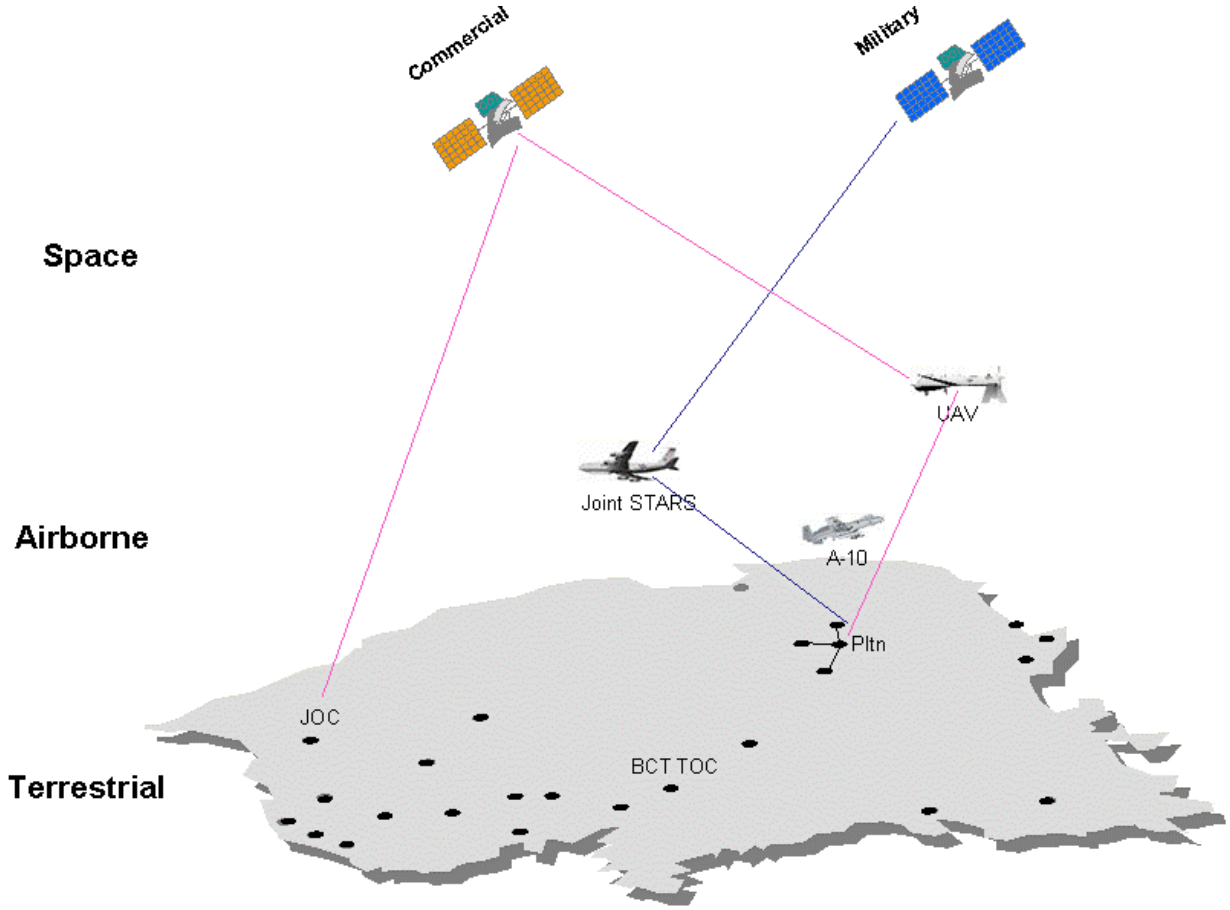


Figure 26: Possible Connectivity 2.

In another example, the platoon is unable to transmit to anyone further away than the A-10s providing close air support. The network routes traffic to the A-10 for transmission to the JOC. The network recognizes inbound commercial satellite transmissions to the platoon are successful and through the relay back to the A-10s, the loop is completed. For that moment, traffic is routed to the TOC to be transmitted to the satellite to be relayed to the platoon. The A-10s are also able to gather the latest intel directly from the UAV. These minor examples provide some insight into the

numerous connectivity options that might be exercised and simulated to gain more understanding of the complexity of the dynamic network reliability and connection problem, especially in a battlespace setting.

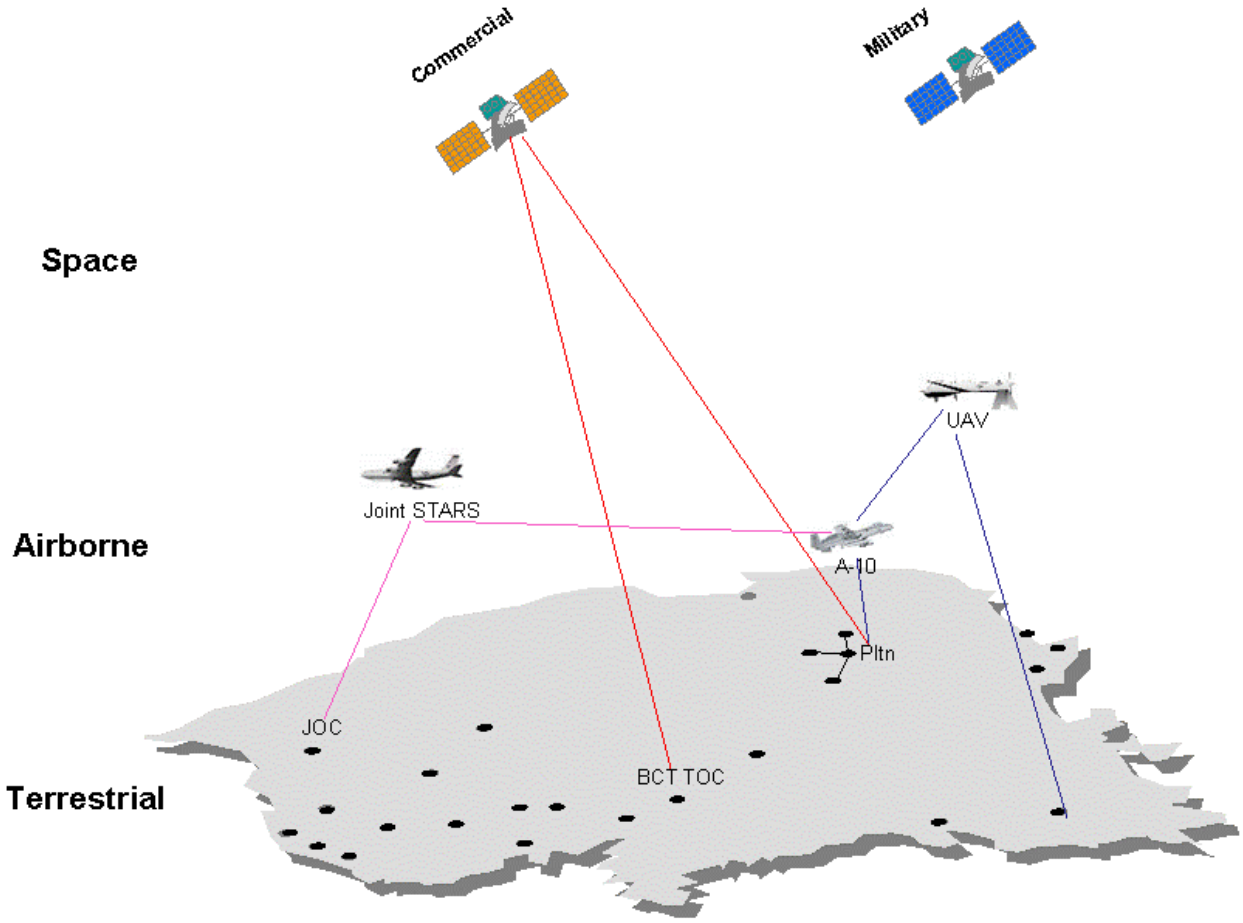


Figure 27: Possible Connectivity 3.

Conclusion

Scholars, engineers and manager have been studying dynamic wireless network technology and the concepts for operations for over 10 years now. The basic concept of opportunistic connections to transport data is old news in the wired world -- for instance in use today on the Internet. The concept of opportunistic connectivity in the

wireless environment is also a mature concept, going back as far as amateur radio operators have used the airwaves to communicate with others around the world. What makes this research area challenging and complex is relying on dynamic, opportunistic connectivity for vital and in the military sense, mission critical communications, to move time-sensitive data and achieve the high data transport reliability enjoyed today.

For this concept to be accepted and widely employed in military applications -- it must be shown in testing and simulation to be able to provide connectivity at the same reliability rate enjoyed by the stationary, point-to-point communications network in place today. Just as the military moved away from leased, dedicated, point-to-point circuits between bases and connected systems and applications directly over the Internet, one day the military will move to dynamic wireless networks to reduce the amount of equipment sent forward into the battlespace and also to better leverage the communications capabilities and capacities found there. However, without strong research data and exercises that conclusively show such a network will provide the reliability required, the move to greater employment of dynamic networks will be slow. This paper provides a background and data to build a notional battlespace for testing and simulating the use of dynamic networks within the US military.

BIBLIOGRAPHY

1. Royer, E. M. Toh Chai-Keong. "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks," Personal Communications, IEEE, 46, April 1999.

2. Bunker, Robert J. "Five-Dimensional (Cyber) Warfighting: Can the Army After Next be Defeated Through Complex Concepts and Technologies?" US Army War College, Strategic Studies Institute, Carlisle Barracks PA 1998.

3. United States Joint Forces Command, "Effects-Based Operations," White Paper, Norfolk VA, 12, 4 October 2002. Also Department of Defense. Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms, page 71, 12 April 2001 (As Amended through 20 March 2006).

4. Adapted from Army Field Manual 3-21.31, The Stryker Brigade Combat Team, Figure 1-4, 13 March 2003.

5. Gonzales, Daniel and Others. Network-Centric Operations Case Study, The Stryker Brigade Combat Team. RAND National Defense Research Institute, Page 31 and Figure 4-1, 2005.

6. Jones, Keith A. and Others. "Integrating Land Warrior into the Army Battle Command System," Briefing. General Dynamics C4 Systems, ISSO December 2004

7. Gonzales, Daniel and Others. Network-Centric Operations Case Study, The Stryker Brigade Combat Team. RAND National Defense Research Institute, 46, 2005.

8. Mills, Robert F. Class Handout, EENG 651, C4 Systems. School of Engineering and Management, Air Force Institute of Technology, Wright Patterson AFB OH, Spring Quarter 2006.

9. Air Force. "A-10/OA-10 Thunderbolt Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.

10. Air Force. "F-16 Fighting Falcon Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.

11. Boeing. Program Management Office Webpage. http://www.boeing.com/defense-space/infoelect/e3awacs/index.htm, 2 May 2006.

12. Air Force. "E-8C Joint Stars Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.
13. Air Force. "KC-135 Stratotanker Fact sheet," May 2006. http://www.af.mil/factsheets/index.asp.

14. Air Force. "MQ-1 Predator Unmanned Aerial Vehicle Fact sheet," October 2005. http://www.af.mil/factsheets/index.asp.

15. Air Force. "Global Hawk Fact sheet," October 2005. http://www.af.mil/factsheets/index.asp.

16. Mills, Robert F. Class Handout, EENG 651, C4 Systems. School of Engineering and Management, Air Force Institute of Technology, Wright Patterson AFB OH, Spring Quarter 2006.

17. Air Force. "Defense Satellite Communications System Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.

18. Air Force. "Global Positioning System Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.

19. Air Force. "Milstar Satellite Communications System Fact sheet," October 2005 http://www.af.mil/factsheets/index.asp.

20. Staats, Steve, Major. Graphic adapted from presentation entitled “Tasking, Collection, Processing, Exploitation and Dissemination (unmanned aerial vehicles) (TCPED) for ISR”, Air Force Institute of Technology (unpublished) 14 May 2004.

21. Department of Defense. Joint Publication 1-02, "DOD Dictionary of Military and Associated Terms. As amended through 31 August 2005.

22. Brumbaugh, David A. "The Parallel Air Tasking Order: Reducing the Size of the Air Operations Center," 2004 Command and Control Research and Technology Symposium, The Power of Information Age Concepts and Technologies, pages 5-6, Jun, 2004.

23. FAA. Air Traffic Publication 7610.4, Special Military Operations, para 10-6-1, February 2004, change 1, August 2004.

24. Department of Defense. Joint Pub 3-0, Doctrine for Joint Operations, GL-7, 10 September 2001.

25 Keuhlen, Daniel T. "Tex", and Others. "The Common Operational Picture in Joint Vision 2020: A Less Layered Cake," Joint Forces Staff College, Joint and Combined Warfare School, page 3, May 2002.

26. Robinson, Bruce T. "Who Goes There?", IEEE Spectrum, page 3, 2003. “Qualcomm’s OmniTRACS network is an equipment management system that simultaneously tracks hundreds of thousands of commercial trucks throughout North America. OmniTRACS is also used to track shipments of nuclear material and transfers of prisoners. Each OmniTRACS vehicle is equipped with a satellite antenna an internal GPS, plus a display sending and receiving text messages. At defined intervals, typically every five minutes, the antenna automatically sends a position report to a Ku-band satellite (10.7 to 18 GHZ) which bounces the signal to Qualcomm’s hub in San Diego, CA. From there, the signal gets routed through the internet to the truck fleet’s management facility. Messages being exchanged between the trucks and their headquarters also follow this path; the Qualcomm network fields some 7 million messages a day.”

27. Robinson, Bruce T. "Who Goes There?", IEEE Spectrum, page 3-6, 2003.

28. Elbonia is a fictional country first introduced to me by Lt Col Matthew Bohn, AFIT Physics Department during mid-term and homeworks.

29. Link 16 Systems Course, F-16 MIDS Fielding Team, TGN SPO ESC/NI3, Hanscom AFB, MA 2004.

Data Flow Matrix

Asset	Description	Data Rate (avg/bursty)	Stryker Platoon	Stryker BN TOC	F-16s	A-10s	Predators	Global Hawk	JSTARS	KC-135	HHQs	AWACS
Stryker Platoon	FBCB2 System data	10 kbps/ 56kbps bursty		X					X		X	X
	Targeting data	2 kbps; 25kbsp bursty	X	X		X			X		X	X
	Collaboration	2kbps 56kbps bursty	X	X		X			X			
	Blue Force Tracking	100 kb every two minutes	X	X	X	X			X		X	X
Stryker Battalion TOC	FBCB2 (low)	10 kbps/ 56kbps bursty	X						X		X	X
	FBCB2 (High)	1 to 8 Mbps							X		X	X
	Blue Force Tracking	100 kb every two minutes	X	X	X	X			X		X	X
	Pushed ISR	10 kbps 56 kbps bursty	X			X			X			
F-16s	Target data	14 kbps 56 kbps		X	X	X			X		X	X
	Ground Coord	14 kbps 56 kbps	X	X					X			
	Mission plan/dev	128 kbps			X	X			X	X	X	X
	ISR/LATRN	28 kbps 1 Mbps	X	X					X		X	X
A-10s	Target data	14 kbps 56 kbps	X	X	X	X			X		X	X
	Ground Coord	14 kbps 56 kbps	X	X					X			
	Mission plan/dev	128 kbps			X	X			X	X	X	X
	ISR/LATRN	28 kbps 1 Mbps	X	X					X		X	X
Predators	Local ISR data, mapping	1Mbps stream		X					X		X	X
	Strategic ISR data	up to 8 Mbps							X		X	X
Global Hawk	Comm Relay only in this scenario											
JSTARS	Ground target data	14 kbps 56 kbps	X	X	X	X			X		X	X
	Mission Plan/dev	128 kbps			X	X			X	X	X	X
	FBCB2 Low	10 kbps/ 56kbps bursty	X	X								
	FBCB2 High	1 to 8 Mbps		X							X	X
	Blue Force Tracking	100 kbps stream (collects all data)	X	X	X	X			X		X	X
KC-135	Mission Plan/dev	128 kbps			X	X			X	X	X	X
	Comm Relay (Primarily)											
Higher HQs	Mission plan, dir, dev (low)	10 pps 100 pps bursty		X		X						
	Mission plan, dir, dev (high)	50 pps 200 pps bursty			X				X	X	X	X
	ISR push (high)	1 to 8 Mbps	X	X					X		X	X
AWACS	Ground target data	14 kbps 56 kbps	X	X		X			X		X	
	Mission Plan/dev	128 kbps			X	X			X	X	X	X
	Air Battle update	128 Kbps 8 Mbps		X	X	X			X	X	X	X

Communications Capacity Matrix

Asset	Capacity and description	Range
Stryker Platoon		
RF UHF Radio	Up to 28.8 kbps bandwidth depending on LOS factors	10-15 km
RF UHF Radio	60 kbps	15-20 km
TacSAT	Up to 1Mbps Receive Only (GBS)	N/A
RF UHF Radio	60 kbps	
Stryker Battalion TOC		
RF UHF Radio	Up to 28.8 kbps bandwidth depending on LOS factors	10-15 km
RF UHF Radio	60 kbps	15-20 km
TacSAT	Up to 8 Mbps send and receive	30 km to 10K km
	Capable of using Global Hawk Comm Relay available 25%	
F-16s		
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
A-10s		
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
Predators		
RF UHF	Up to 1 Mbps	100 km (in the air)
SatCom	up to 8 Mbps	unlimited
	Capable of using Global Hawk Comm Relay available 25%	
Global Hawk	Comm Relay Package	
RF UHF	Up to 256 Kbps	100 km
SatCom	Up to 8 Mbps	unlimited
Comm Relay RF	Up to 2 Mbps	200 km
KC-135		
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
Comm Relay RF	Up to 2 Mbps	200 km
JSTARS	Track 06	10KM
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
AWACS		
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
Comm Relay RF	Up to 2 Mbps	200 km
SatCom	Up to 8 Mbps	unlimited
HHQ		
RF UHF Radio	Up to 28.8 kbps to other UHF in range	75 km (in the air)
RF VHF Radio	Up to 14.4 kbps to other aircraft in range	75 km (in the air)
Tactical Data Link	Up to 1 Mbps to other Tactical Data Link equipped platforms	75 km (in the air)
Comm Relay RF	Up to 2 Mbps	200 km
SatCom	Up to 8 Mbps	unlimited

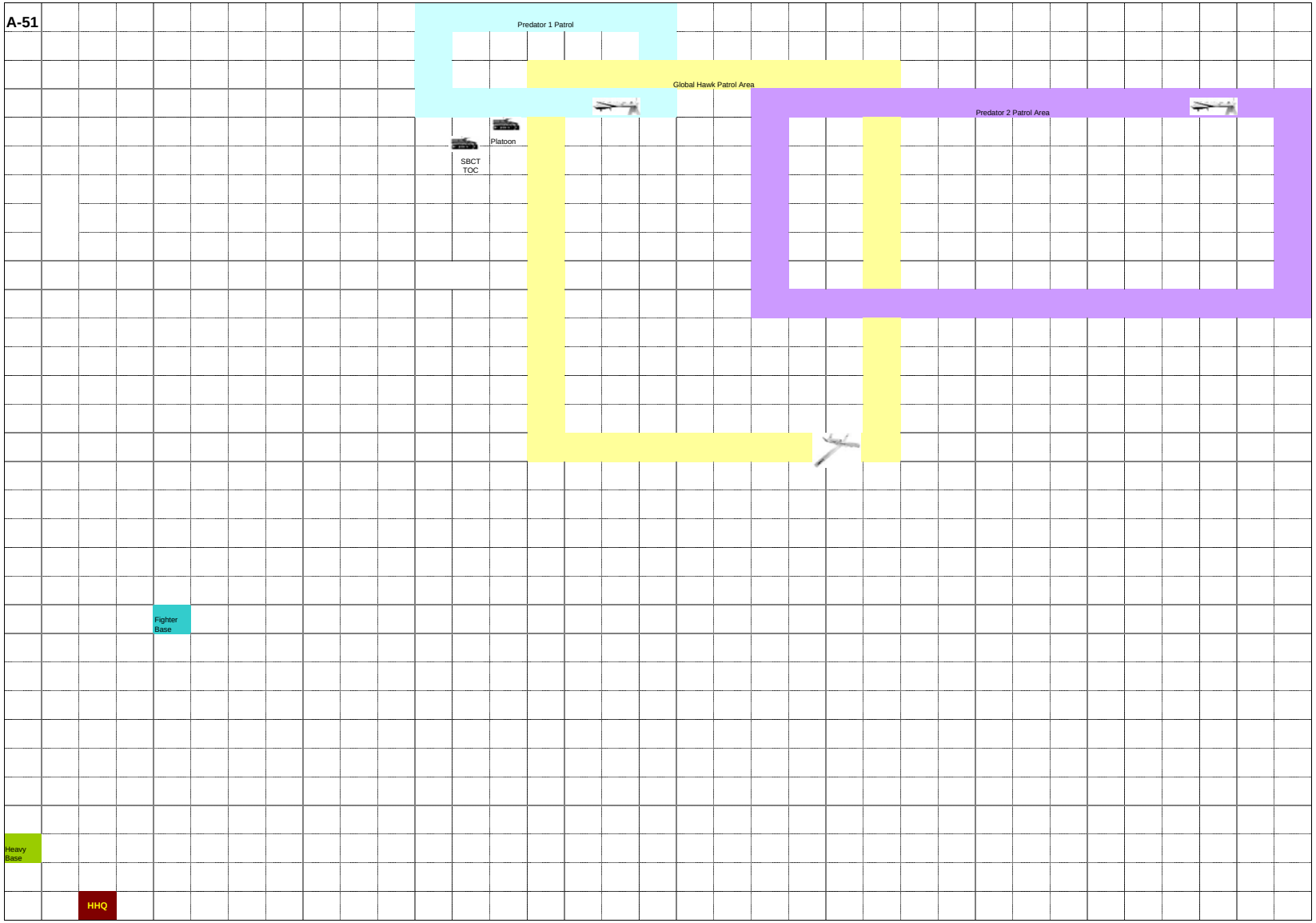
Notional Battle Rhythm Matrix

Asset	Initial Location	5:00 AM	8:00 AM	9AM	10AM
	(Map Grid)				
Stryker Platoon	N-55	Moving to O-52 by Noon			
Stryker BN TOC	M-56	Moving to N-53 by Noon			
F-16s	E-72 (Home Station)			Wheels up; headed to B-60 for fuel	Strike mission to Q-35
A-10s	E-72 (Home Station)				Wheels up; headed to loiter/CAS over Pltn
Predator 1	Track L-40 to L-54 X R-40 to R-54				
Predator 2	Track U-54 to U-61 X AI-54 to AI-61				
Global Hawk	Track O-53 to O-66 X X-53 to X-66				
JSTARS	A-80 (Home station)				Wheels up; headed to diagonal track J-56 to R-66
KC-135	A-80 (Home station)		Wheels up; headed to track B-56 to B-66; tight oval		
Higher HQs	C-82				
AWACS	A-80 (Home station)				

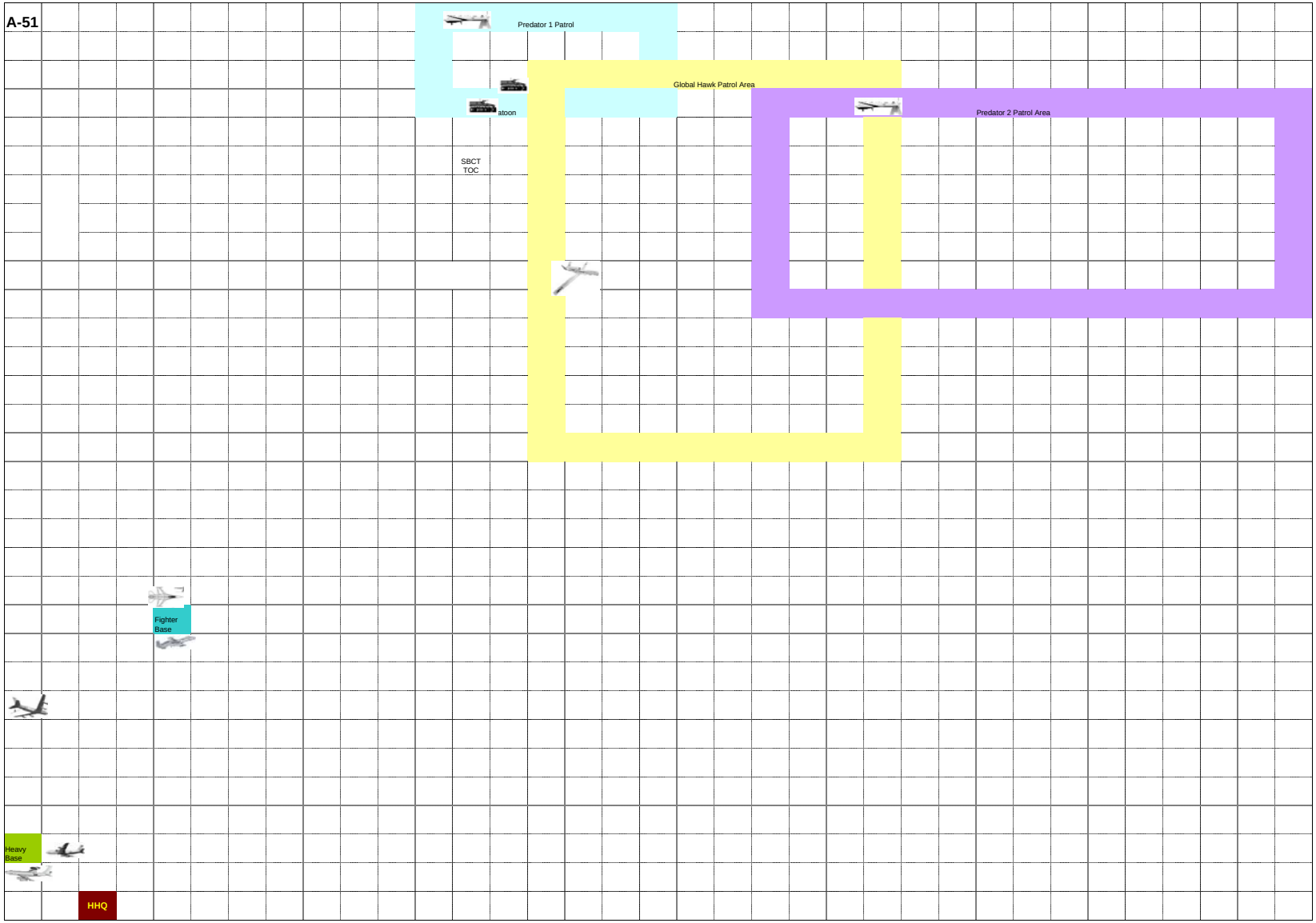
Notional Battle Rhythm Matrix

Asset	12PM	1PM	2PM	4PM	6PM		8PM
Stryker Platoon	O-52			P-50	O49		
Stryker BN TOC	N-53		O49		O48		
F-16s	Rtn B-76 reload	Wheels up; headed to B-60 for fuel; then loiter over Pltn					B-76 (Home Station)
A-10s		Rtn Station		Wheels up; headed to loiter/CAS over Pltn			B-76 (Home Station)
Predator 1							Track L-40 to L-54 X R-40 to R-54
Predator 2							Track U-54 to U-61 X AI-54 to AI-61
Global Hawk							Track O-53 to O-66 X X-53 to X-66
JSTARS					RTN to Station		A-80 (Home station)
KC-135					RTN to Station		A-80 (Home station)
Higher HQs							C-82
AWACS							A-80 (Home station)

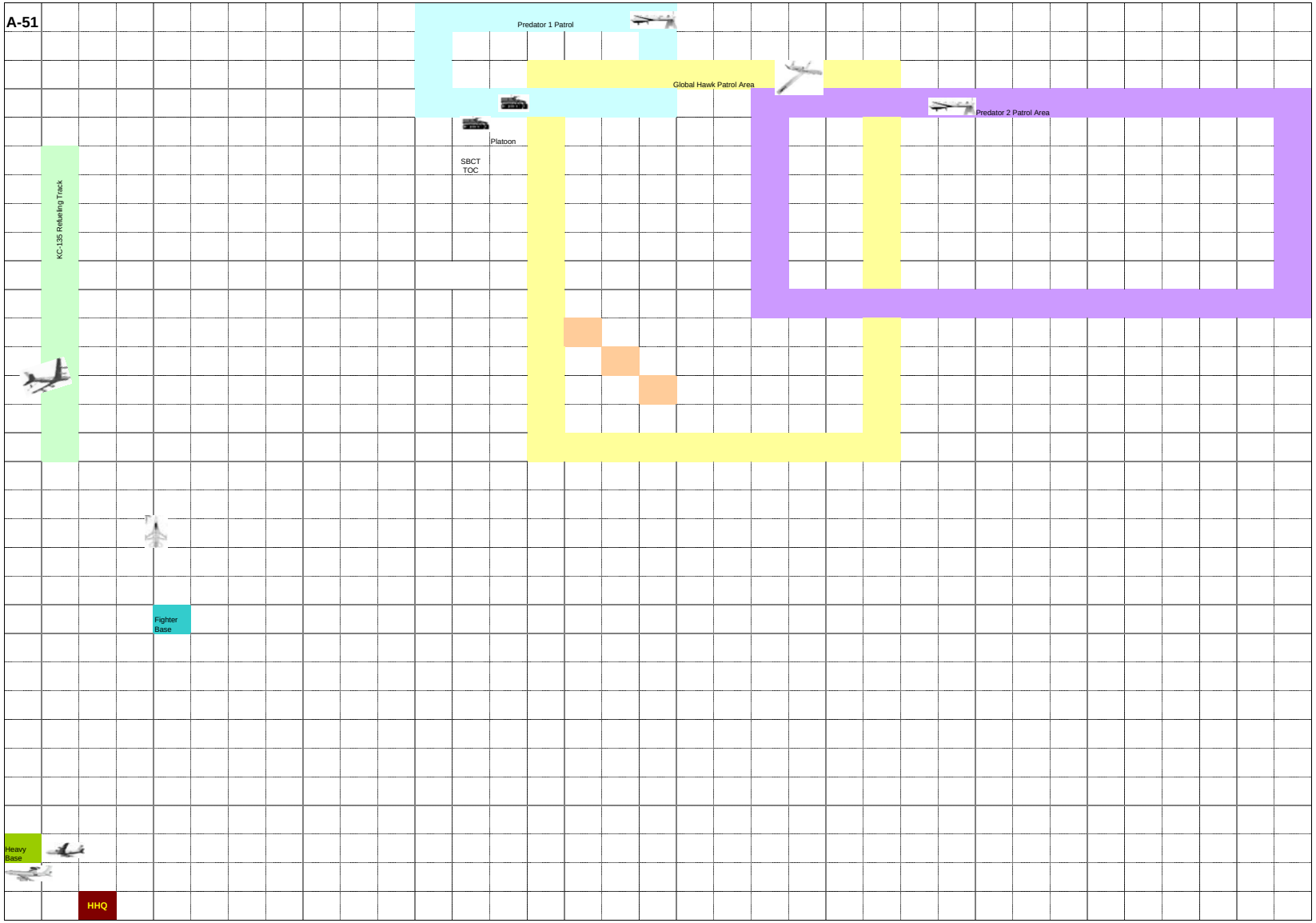
Graphic Location 0500
Each grid line represents 10 km



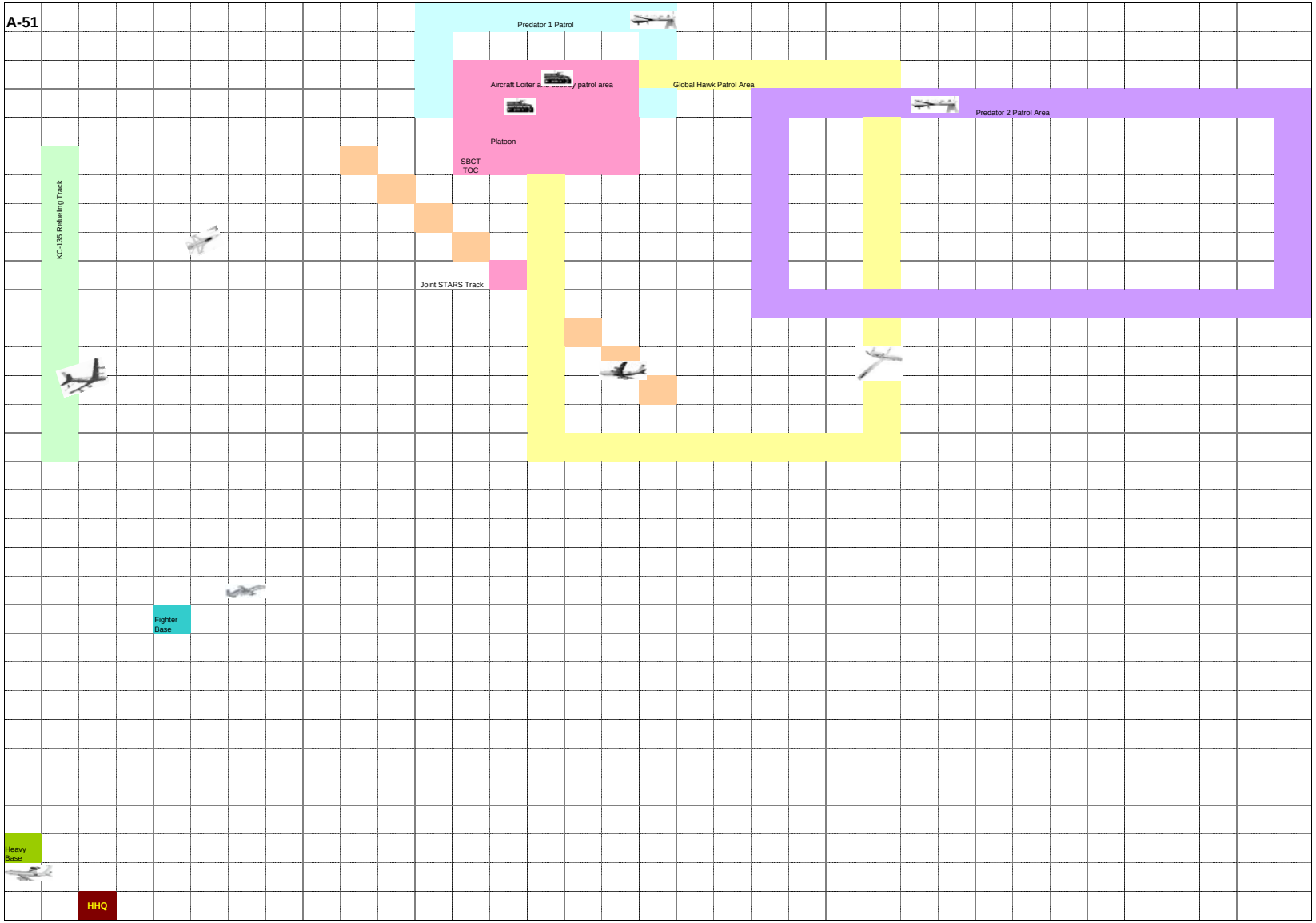
Graphic Location 0800
Each grid line represents 10 km



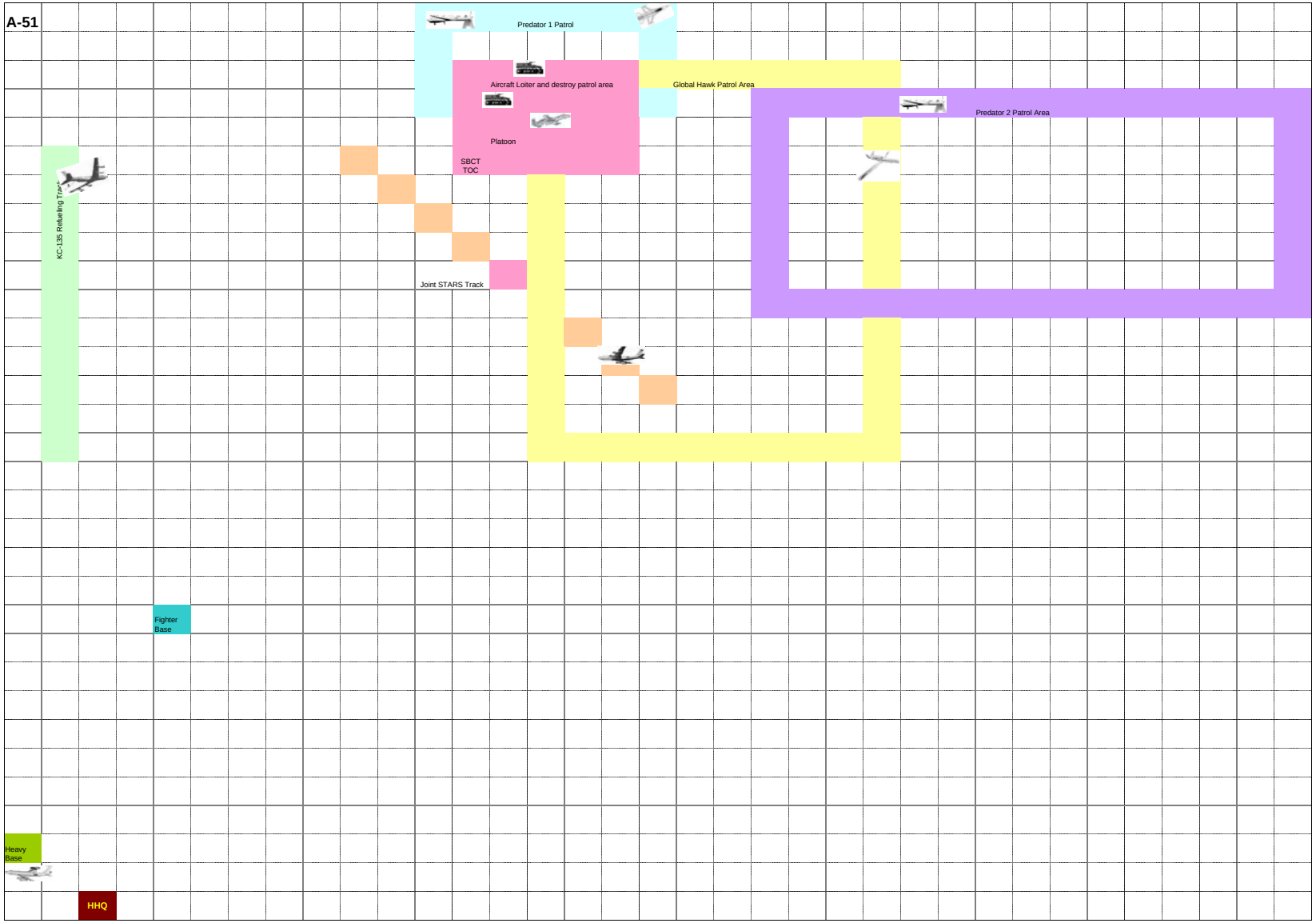
Graphic Location 0900
Each grid line represents 10 km



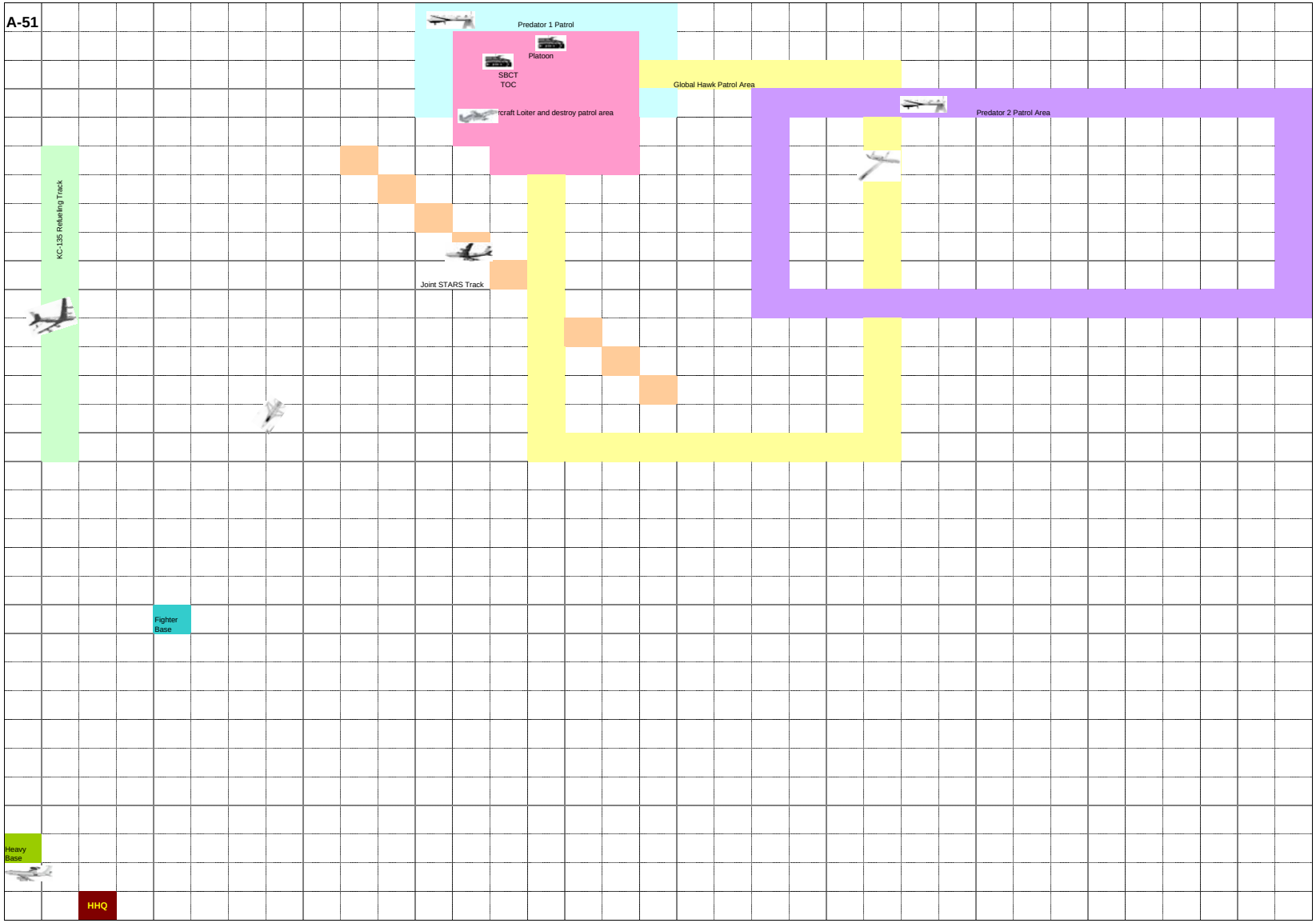
Graphic Location 1000
Each grid line represents 10 km



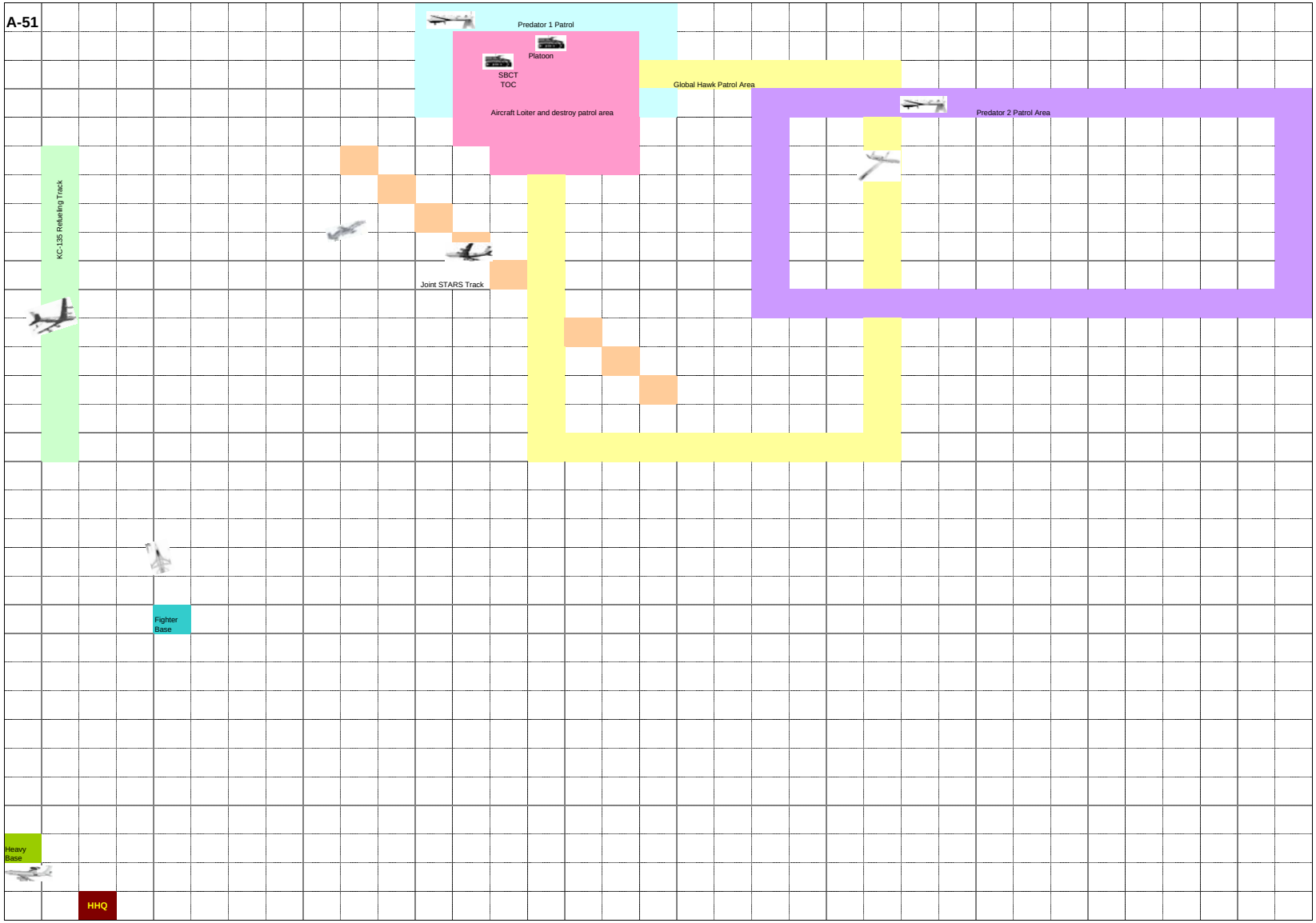
Graphic Location 1100
Each grid line represents 10 km



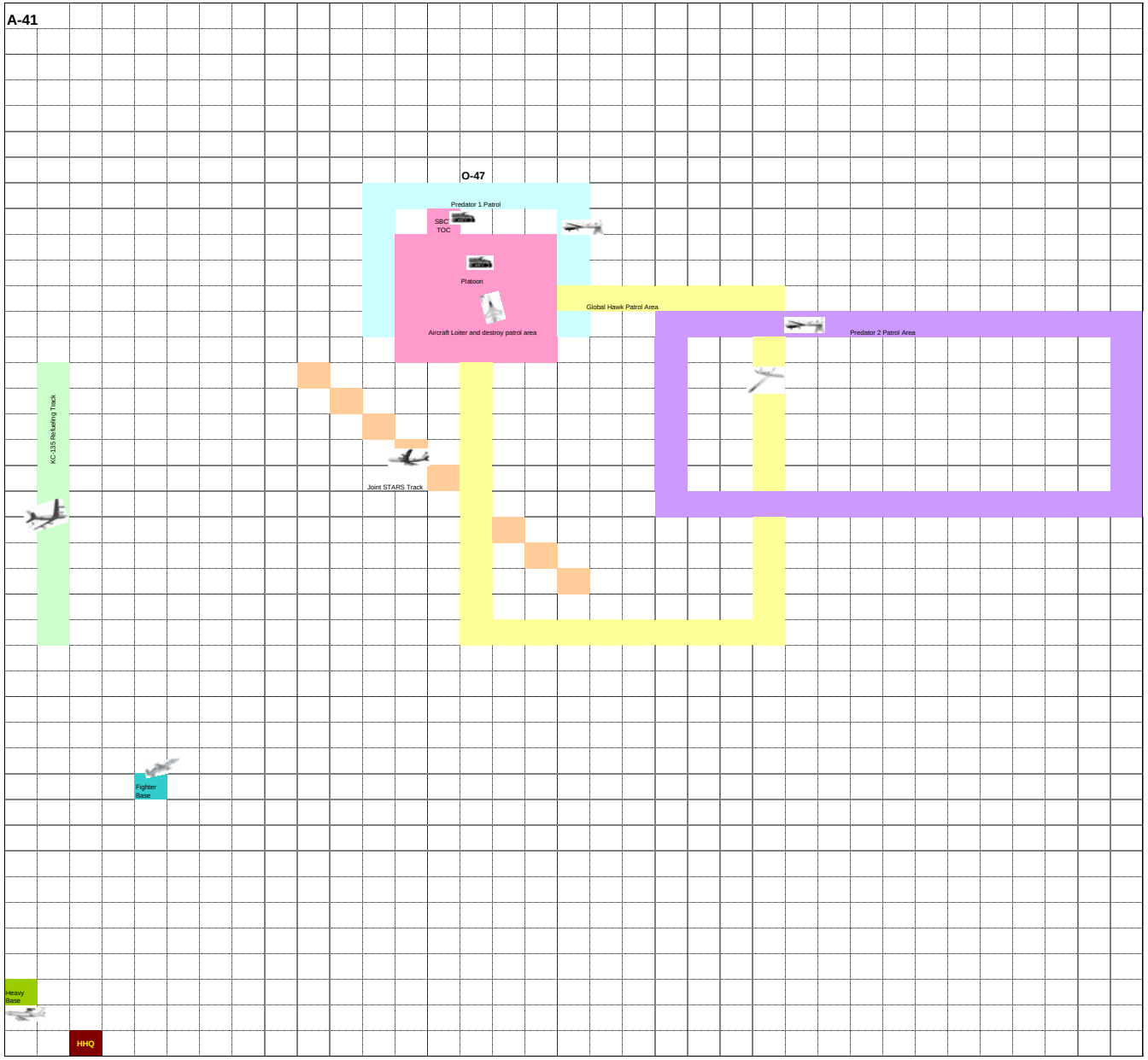
Graphic Location 1200
Each grid line represents 10 km



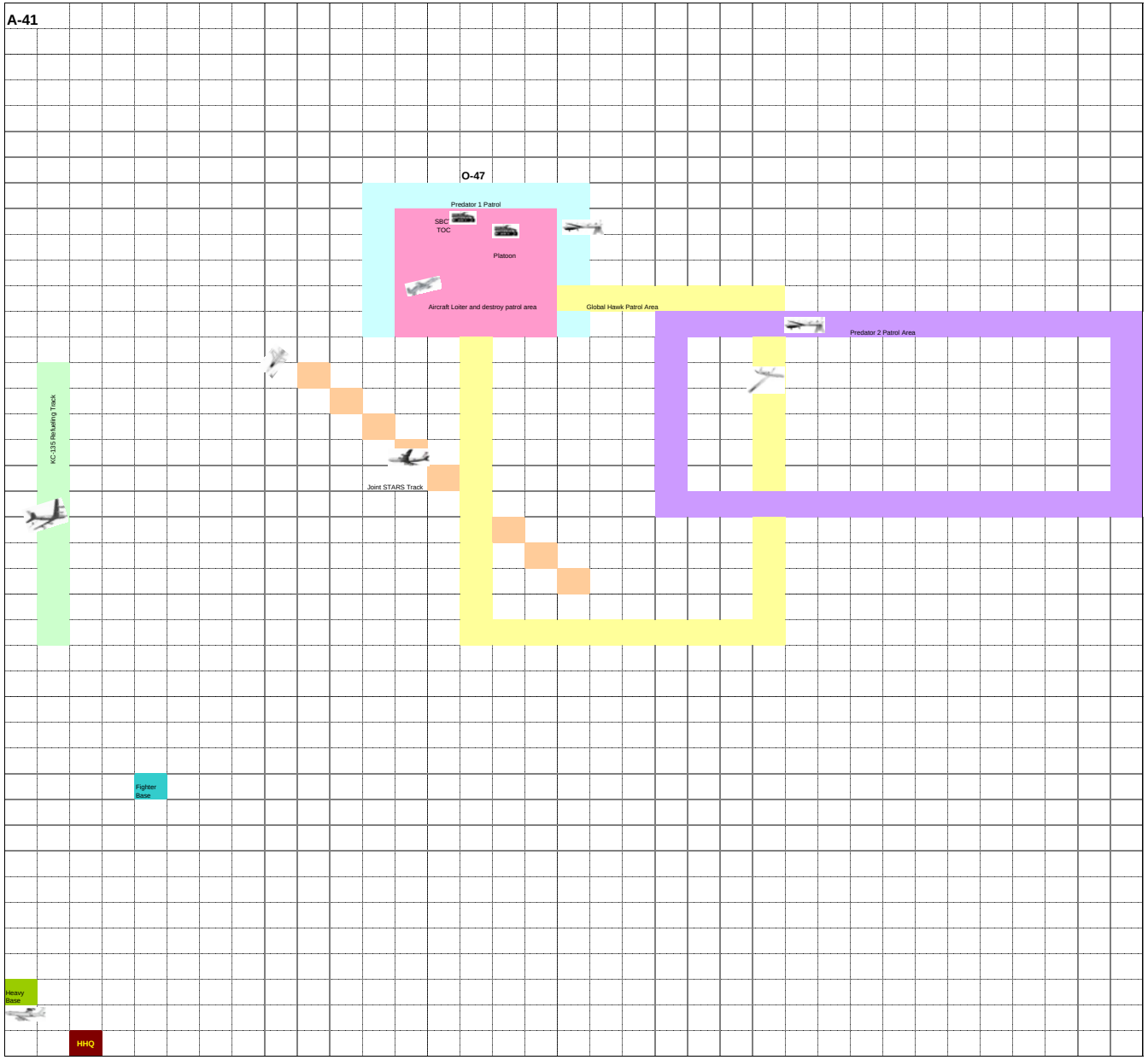
Graphic Location 1300
Each grid line represents 10 km



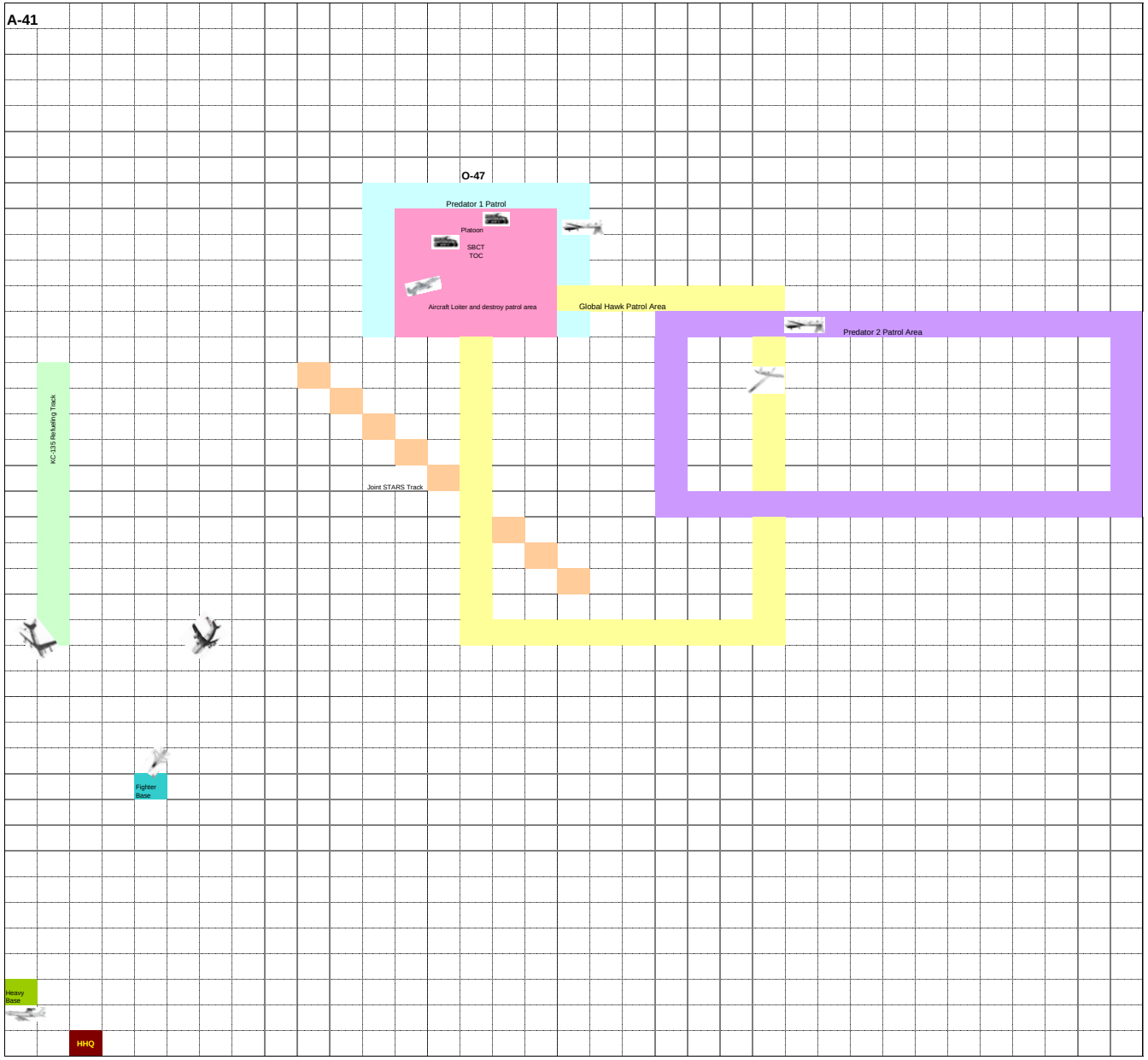
Graphic Location 1400
Each grid line represents 10 km



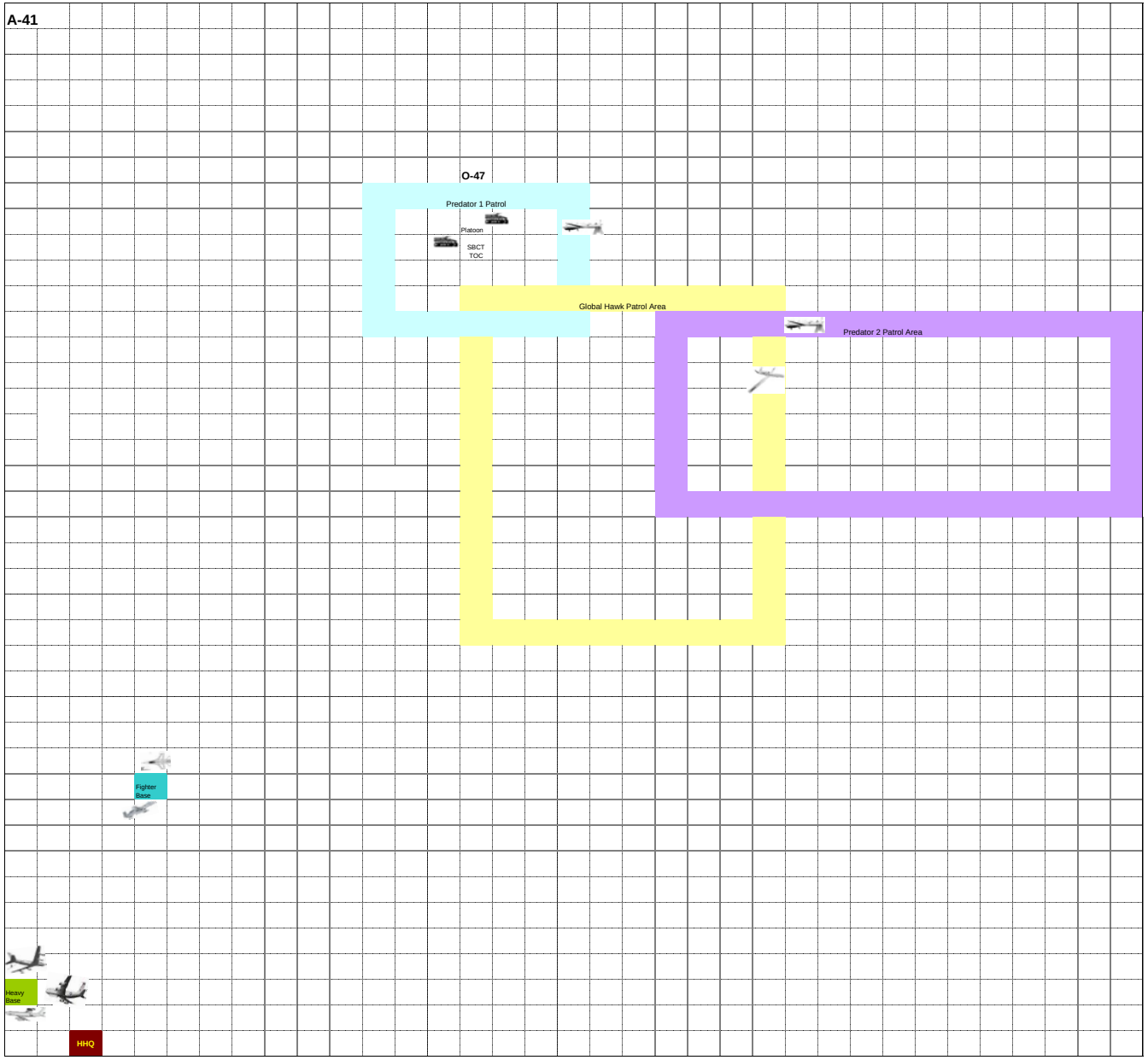
Graphic Location 1600
Each grid line represents 10 km



Graphic Location 1800
Each grid line represents 10 km



Graphic Location 2000
Each grid line represents 10 km



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to an penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	
13-06-2006	Graduate Research Project	Mar 2006 – Jun 2006

4. TITLE AND SUBTITLE

A Notional Battlespace for Simulating and Testing Dynamic Wireless Networks

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Stookey, David E., Major, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/IC4/ENG/06-06

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

N/A

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Communications are critical to many operations and functions. The US military relies on a complex mesh of communication circuits, comprised of wired and wireless links. While mobile communication is necessarily wireless, currently mobile communication occurs in a rigid structure of centrally managed, dedicated links. Future military communication will require dynamic wireless networks where more data is routed and transported in an opportunistic method in the battlespace. Researchers are exploring various topics related to Dynamic Wireless Networks, including Topology Control, Dynamic Mobile Routing, and Hybrid Communication Links. Testing the military application of these research areas requires an understanding of the battlespace and the assets and data flow requirements within the battlespace.
This paper provides a scenario and data pertaining to a notional battlespace for use in testing, simulating and further research efforts into the implementation and use of dynamic wireless network application for the US military. First defining a battlespace, then describing assets that might be found in a generic battlespace. The paper concludes with tables, representing realistic data flow requirements and assets for a specific notional scenario for use in building a simulation to further test aspects of dynamic wireless networking in the battlespace.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Major Scott R. Graham, ENG
U	U	U	UU	86	19b. TELEPHONE NUMBER *(Include area code)* (937) 255-3636, ext 4918 (scott.graham@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18